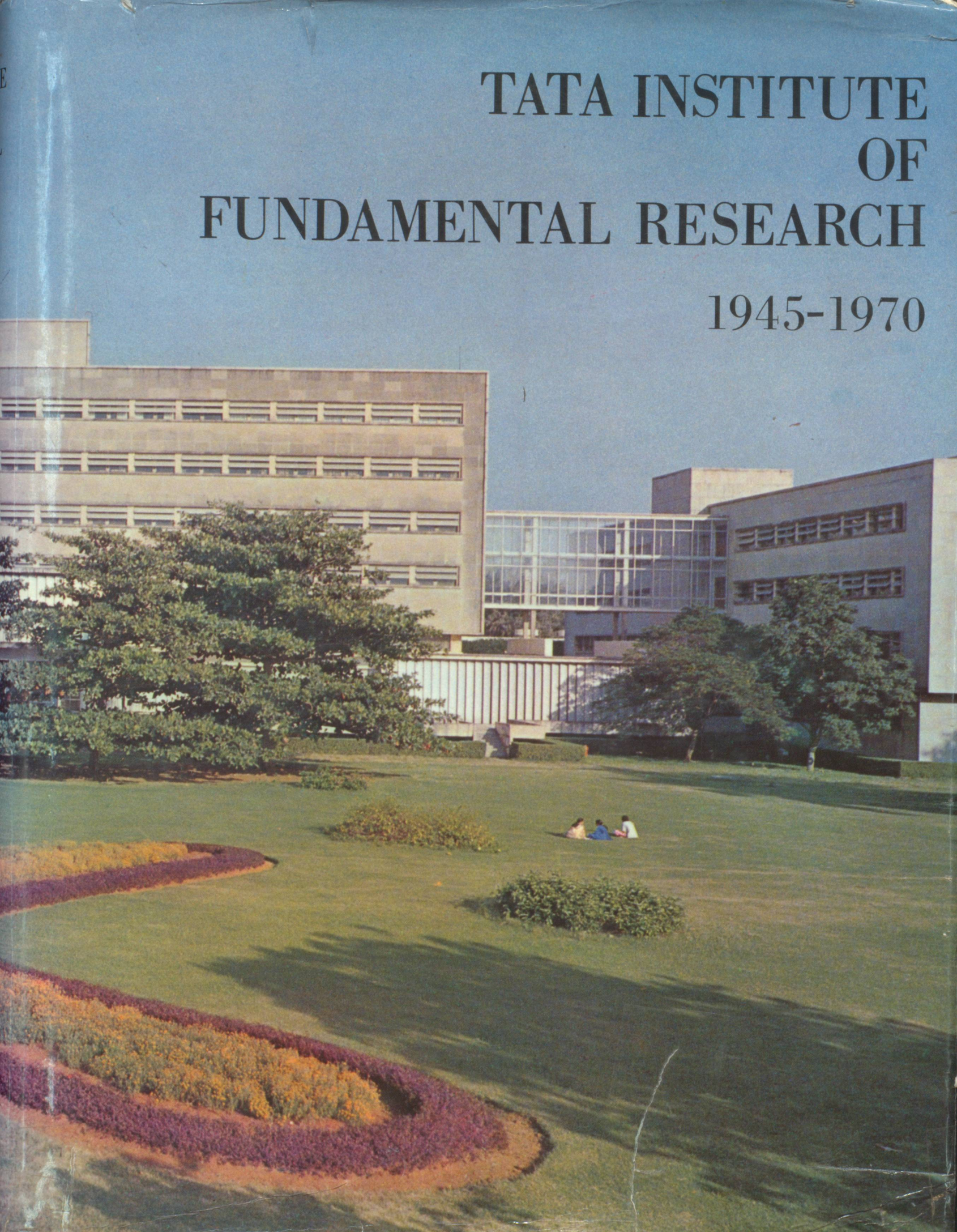
TATA INSTITUTE OF FUNDAMENTAL RESEARCH

1945-1970



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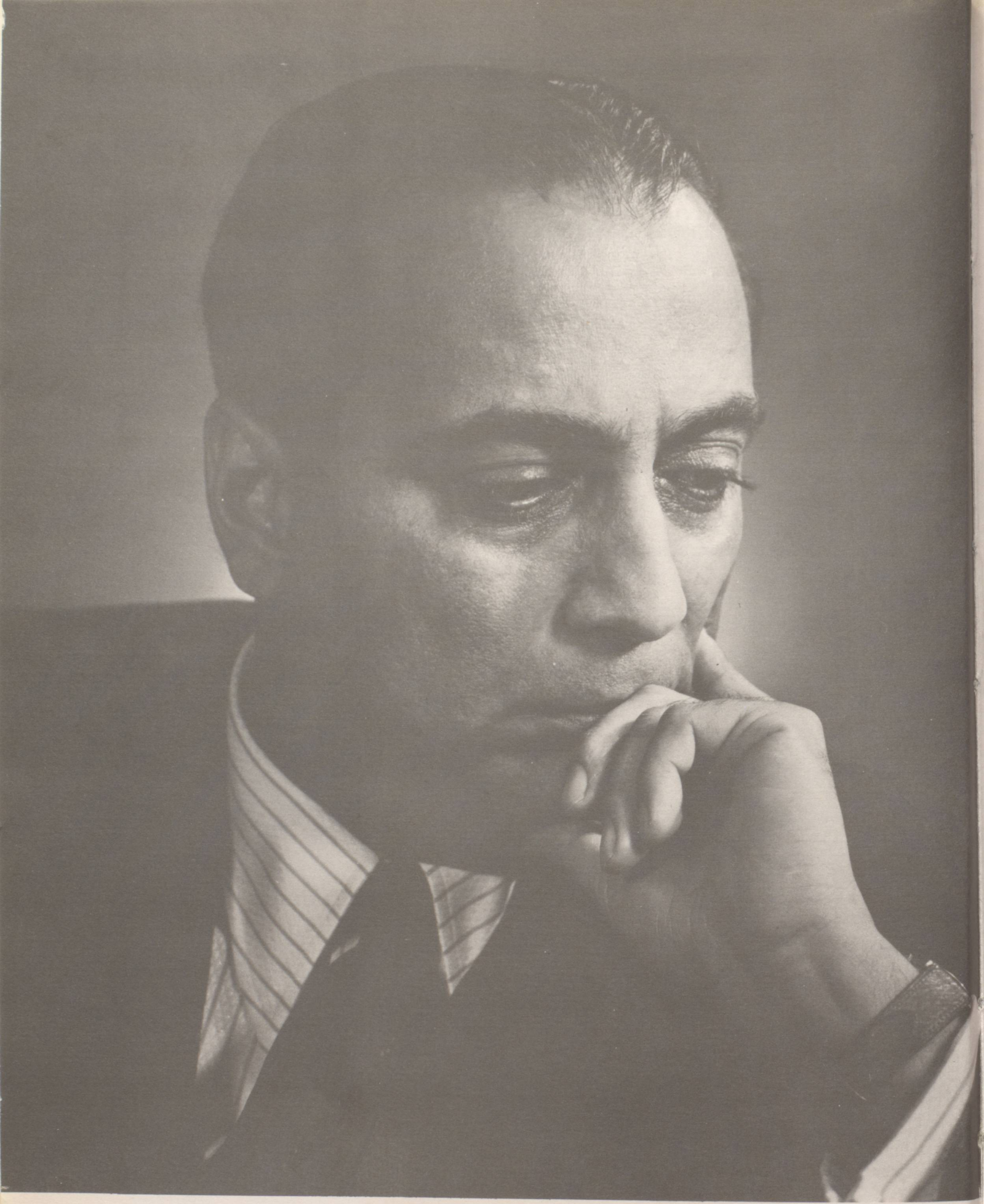
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Photographs by R. R. Bharadwaj and B. D. Upadhyay



Dr. Homi J. Bhabha
(From a photograph by Karsch)

FOREWORD

When I was a young man and shared with thousands of others the dream of a free, modern and industrialised India, the life and struggles, over half a century, of a succession of inspired leaders from Dadabhai Naoroji to Mahatma Gandhi, Jawaharlal Nehru, Vallabhbhai Patel and others convinced me that India's political freedom could not be long delayed and that the time had come for the country to prepare itself to take its destiny in its own hands.

Jamsetji Tata had warned that political freedom would be a delusion without economic strength to support and, if need be, defend it, and that the latter in turn must be based on science and technical education in addition to industry and electric power. He had himself laid the foundations for all three in the industrial projects and the Institute of Science he had sponsored at Bangalore.

As I viewed the troubled scene of the thirties and the formidable problems and dangers ahead, I was convinced that only an elite of brilliant and dedicated men could take the country forward to its high destiny, and that if India was to achieve the rate of progress essential to the welfare of its teeming millions, it must bring to bear to the task the latest advances in science and technology which were transforming so much of the rest of the world. The appearance on the scene of Homi Bhabha in 1943, on his return from Cambridge, with his immensely talented mind steeped in modern science and his prophetic vision of the potential of nuclear energy, seemed a truly predestined one.

He soon saw the need for a fundamental research institute of the highest calibre which would attract to it and train the best talents in the country and harness them to the task of preparing India for the advent of the nuclear age.

When, therefore, he wrote to me for support for the creation of what became the Tata Institute of Fundamental Research, he had very little trouble in convincing me and, through me, my colleagues in Tatas. My close connection with him and with the Institute goes back to those days, and of all the activities in the creation of which I have played some role, in this case a very minor one, there is none of which I am prouder today than the TIFR.

Professor Menon and Professor Sreekantan have admirably described in this volume the genesis and growth of the Institute. There is therefore little for me to add, and this foreword will be very brief and limited to paying renewed tribute to those to whom India owes so much for its remarkable progress in science and technology since Independence.

First, I must of course once again pay tribute to Homi Bhabha whose wide-ranging vision, drive and genius achieved in twenty years a lifetime's work. Then, to his colleagues and successors, outstanding and dedicated scientists, who carried on his great work with the same determination and singleness of purpose. Finally, to Jawaharlal Nehru who, as our first Prime Minister, gave unstinted support to the development of the Institute and other scientific institutions in the land. It is good to know that such support has not been lacking from his successors to whom, as Chairman of the Institute's Council, I would like to express our deep appreciation and gratitude.

The pages that follow tell of expansion, of achievements and of new directions in which the Institute has turned, keeping ever in mind the need for helping the millions of this country to a better life.

The Institute's task will never end, for the frontiers of knowledge will always lie ahead. A relentless pursuit of excellence has characterised and indeed made possible the Institute's achievements, progress and international recognition. May that spirit, instilled in all those who worked with Homi Bhabha, be ever maintained and inspire in the years to come even those to whom he will be but a legend.

J. R. D. Tata

PREFACE

In August 1943, a brilliant young scientist who had returned to India in 1939 in the middle of an outstanding academic career at the Cambridge University to become a Reader and then a Professor at the Indian Institute of Science, Bangalore, and on whom the coveted fellowship of the Royal Society of London had been conferred at the age of 32—the late Dr Homi Bhabha—wrote, what turned out to be, a historic and prophetic letter to the noted industrialist, Shri J. R. D. Tata, seeking his support for the creation of a fundamental research institute in India. The prompt and encouraging response from Shri Tata followed by the support given by the Sir Dorabji Tata Trust and the then Government of Bombay Presidency led to the founding of the Tata Institute of Fundamental Research in May 1945. The Founder Director, Dr Bhabha, guided the course of development of the Institute for 21 years till his untimely death in the tragic air-crash of January 24, 1966. In this period, he not only fulfilled his promise of building an Institute from its embryonic stage to one in which it came to be internationally recognized as a centre of research in Mathematics and Physics and allied sciences, comparable to the best anywhere on the globe, but also used this institution as the cradle for building the Atomic Energy programme of India. Professor M. G. K. Menon, F.R.S., who succeeded Dr Bhabha as Director of the Institute, not only maintained and furthered with distinction the high level of research activity of the Institute but was also largely responsible for the increased involvement and commitment of the Institute in the nationally relevant applied areas of research and development, particularly in the fields of electronics and computer sciences.

The Report whose preparation began in the Silver Jubilee Year 1970-71 gives a comprehensive account of the genesis of the Institute, its historical growth and diverse scientific achievements, the full list of research publications in the various disciplines, the national facilities created by the Institute, its interaction with universities and other scientific institutions in the country etc. While individual sectional reports were prepared by the heads of the various divisions, the onerous and tedious task of integrating, editing and recasting them to conform to a uniform style of presentation was undertaken by Professor M. G. K. Menon, and Professor R. R. Daniel, who was then Dean of the Physics Faculty. Nearly 70 per cent of the report had been finalised by 1972 and the Tata Press who had undertaken the responsibility for printing the report, had also completed much of the work on the preparation of the positives for offset printing. However, due to some unforeseen circumstances, the work on this report had to be suspended for a few years. It was only in October 1976 that the activity was revived and thanks to the enthusiastic and devoted efforts of Dr R. P. Sharma and Mrs M. M. Vajifdar, and the cooperation of the Tata Press, the task has now been completed and the full Report is in your hands.

An abridged version highlighting the Institute's historical background, the philosophy of its growth, the principal scientific work in progress, the environment and the atmosphere in which it grew was published at the time of the Silver Jubilee celebrations of the Institute in April 1971. This abridged report which was so beautifully written by Professor Menon himself, forms the introductory chapter of the present full Report.

Today the Institute is in the forefront of research in Mathematics, Physics, Astronomy, Astrophysics, Molecular Biology, Electronics and Computer Sciences, also it is one of the few institutions in the world which has the climate and provides opportunities by its very structure for the cross-fertilization of ideas among different disciplines—a factor so vital to the progress of many areas of science. In the applied areas apart from operating the National Computer Centre and undertaking projects of national relevance on behalf of governmental agencies like Defence, Railways, Department of Electronics, Department of Space etc. considerable amount of Research & Development work is carried out in the areas of computer sciences, material sciences, solid state electronics and microwave engineering. The Institute also manages the newly established National Centre for Software Development and Computing Techniques and the Homi Bhabha Centre for Science Education. Very many individuals and institutions have contributed towards this phenomenal growth of the Institute. I cannot express their contributions in terms more appropriate than what Professor Menon has done in the Preface to the abridged edition which I reproduce below:

". . . . . .It was the vision of Homi Bhabha which brought it into existence. And in his efforts to set it up and to develop it he had the fullest backing of Shri J.R.D. Tata and Prime Minister Jawaharlal Nehru.

The three parties, the Government of India (in the Department of Atomic Energy), the Government of Maharashtra and the Sir Dorabji Tata Trust, who have jointly taken on the responsibility for the Institute under the Tripartite Agreement, have each given it their fullest support, and displayed throughout an exemplary and sensitive awareness of the needs of an institution engaged in scientific research. For their deep interest, encouragement and unfailing support the Institute would like to place on record its gratitude to the Prime Minister, Smt. Indira Gandhi, the Chairman of the Atomic Energy Commission, Dr Vikram Sarabhai, and to the many officers of the Department of Atomic Energy who have been closely concerned with the Institute; to the Government of Maharashtra, in particular the successive Chief Ministers, Shri Y. B. Chavan and Shri V. P. Naik, and the many officers who have served on the Council of Management; and to the Trustees of the Sir Dorabji Tata Trust, particularly Professor Rustom Choksi, who has been a Member of the Council of Management for 21 years. These have all given of their time and energy, their advice and support, in the fullest measure and thereby played a significant part in the development of the Institute. And particular mention should also be made here of a sister institution, the Bhabha Atomic Research Centre, under its Director Shri H. N. Sethna, who have been with the Institute in all that it has attempted and accomplished.

In the ultimate analysis every institution is a creation of the men and women who work in it. This Institute has been particularly fortunate in its staff; as important as the qualities of intellect have been the other attributes of loyalty, dedication, and most

of all the manner of functioning together as one family.

As an institution engaged in fundamental research, the Institute is part of the international scientific community; and in this community the Institute has received friendship, advice and recognition which have been a source of great encouragement in its work; outstanding men of science have visited, lectured and participated in the work here, and the Institute is honoured that several of these figure in its list of Honorary Fellows.

In all respects, the Insitute has much to be grateful for when it looks back at the first twenty-five years of its existence; and on the occasion of the Silver Jubilee it looks forward with hope to the years ahead with full confidence that it will be able to contribute in an important measure to the advancement of science, to the development of the nation and to the well being of society."

B. V. SREEKANTAN
Director

SOME TRIBUTES TO DR. HOMI BHABHA

"Human progress has always depended on the achievement of a few individuals of outstanding ability and creativeness. Homi Bhabha was one of them"

Sir John Cockroft

"Affectionate and sensitive, elegant and humorous, dynamic, one of the very few people who enhance life whatever the content of their living—fantastically talented but so fastidious about standards that he was never a dilettante. Whatever he set himself to do, he did as a professional—but one who worked for love; restlessly creative, enhancing life because he loved all forms of it. So he became a living proof that scientific excellence can go with excellence in art, and racial differences need be no bar to friendship. He stood out as a world citizen qualified in all three subjects—education, science and culture"

Lord Redcliffe-Maud

"Homi was surely, in a sense, a man out of his own time. He had the wide breadth of interests, the penetrating intellect, the abounding personal confidence in the ability of the human understanding, by observation and experiment, to unravel the secrets of nature, which are characteristic of the great figures of the Renaissance. But perhaps such figures have an essential creative role to play in all ages"

Cecil F. Powell

"Homi Bhabha . . . a legendary figure in his own lifetime, working towards the end with an urgency which had to be seen to be believed, working against time when he felt he had so much to accomplish"

M.G.K. Menon



Mr. J. R. D. Tata

INTRODUCTION

Genesis of the Institute

The Tata Institute of Fundamental Research was founded in June 1945 by the Trustees of the Sir Dorabji Tata Trust in co-operation with the then Government of Bombay. The initiative to set up such an Institute was taken by Homi Bhabha in 1943. In this Report, which is concerned with the activities of the Institute during the first quarter of a century of its existence, it would be appropriate to recall, and to place on record, the various steps and factors that led to the establishment and subsequent growth of the Institute.

Letter from Homi Bhabha to J. R. D. Tata

19th August 1943

In a letter dated 19th August 1943 to Mr. J. R. D. Tata, Homi Bhabha pointed out that:

> *"the lack of proper conditions and intelligent financial support hampers the development of science in India at the pace which the talent in the country would warrant".*

In particular, he was concerned that the lack of support operated adversely in several ways: firstly, it did not provide men who have chosen a scientific career, with the necessary equipment, facilities and environment for doing research; secondly, by throwing too great an administrative burden and teaching load on their shoulders, it did not leave them enough time and energy for advanced study and research; and thirdly, the poor conditions of work and the poor financial prospects of a scientific career induced many of the most able university men to take up an administrative or commercial career. In the same letter to Mr. J. R. D. Tata, Homi Bhabha pointed out that if Indian science was to progress, far greater financial support was needed for "pure" or "fundamental" research, which was not likely to give any immediate economic return. He emphasised that even in the Soviet Union, where the stress was on gearing scientific research and development to economic and social problems, nevertheless, fundamental research was also strongly supported, for, in the official Soviet view:

> *"there is no genuine knowledge of the universe that is not potentially useful for man, not merely in the sense that action may one day be taken on it but also in the fact that every new knowledge necessarily affects the way in which we hold all the rest of our stock".*



Fig. 2—Jawaharlal Nehru, Homi Bhabha, J.R.D. Tata and Rustom Choksi.

Homi Bhabha: his background and aspirations

To appreciate this initiative on the part of Homi Bhabha, it would be useful to recall briefly his career and aspirations. Homi Bhabha spent 13 of the most impressionable years of his youth in the west, from the age of 17 to 29. He had worked in Cambridge, England in the heady atmosphere of the physics of the 1930s, a decisive and most fruitful period in the history of theoretical physics, nuclear physics and cosmic ray physics, and had associated himself with some of the great names in physics of this century: Blackett, Chadwick, Dirac, Heitler, Kapitza, Rutherford and others in England, and elsewhere in Europe with Bohr, Fermi, Kramers and Pauli. During this period, he had established himself as a theoretical physicist in the front rank, with work of great originality which was internationally known; and had also established a broad and high level base of cultural interest, notably in music, painting and architecture. Homi Bhabha was on a holiday in India in 1939, when owing to the out-break of the Second World War and the consequent changes which occurred in England he could not return to Cambridge to continue the work that he was doing. Therefore, in 1940, he accepted a position at the Indian Institute of Science in Bangalore as Reader (and later Professor) in charge of a special cosmic ray research unit, which was set up for him by the Sir Dorabji Tata Trust.

In the rapidly developing frontier areas in which he had worked for almost a decade in Europe, Homi Bhabha was all by himself in Bangalore; and he knew that these areas of nuclear physics, elementary particle high energy physics, cosmic rays and associated theoretical physics, had just opened up; and would flower with great possibilities for conceptual and fundamental breakthroughs as well as in terms of their applications. He further realised that it would be

necessary to provide a fair amount of financial support in order to train and to provide opportunities for work for a sufficient number of scientists in these modern areas; and that it was only from such a base that one could hope to make real progress.

Homi Bhabha was an extrovert and a dynamic personality with a great deal of drive and energy. And he believed that he could, provided the right type of support and encouragement were forthcoming, develop new sophisticated areas of science and technology in the country, and equally important, harness these developments to achieve economic prosperity and social change. He had established an identity between himself and his country, and wanted to remain in it and play his role in its development. In order to do this, he felt it was essential to set up a new institution, concerned with scientific development in the topical, sophisticated and frontier areas of science and technology, with modern concepts of administration and research management, which had an atmosphere and environment conducive to the growth of a scientific community and of self confidence, and which would act as a pace-setter and be the base from which major ventures could be undertaken. Many of these thoughts are contained in scattered correspondence and writings of Homi Bhabha; and one comes across phrases such as:

> *"would have an electrifying effect on the development of science in India"; "build up in time an intellectual atmosphere approaching what we knew in Cambridge and Paris"; "it is the duty of people like us to stay in our own country and build up outstanding schools of research such as some other countries are fortunate to possess"; etc.*



Fig. 3—Homi Bhabha talking to C.V.Raman at the Indian Institute of Science Bangalore.

Lastly, even at that time (1943-44), Homi Bhabha thought of nuclear physics not just as an area of esoteric research, but one that would lead to the controlled uses of nuclear energy, with prospects for abundant and cheap electric power for national development. It was in the light of this background that Homi Bhabha took the initiative to write to Mr. J. R. D. Tata, on 19th August, 1943.



Fig. 4 — Homi Bhabha, 1909-1966.

Letter dated 12th March, 1944 from Homi Bhabha to Sir Sorab Saklatvala, Chairman of the Sir Dorabji Tata Trust

In his reply dated 2nd September 1943, Mr. J. R. D. Tata wrote: "From what you say in your letter, it is evident that there is scope for rendering valuable service to the country and to the cause of scientific research in India. If you and/or some of your colleagues in the scientific world will put up concrete proposals backed by a sound case, I think there is a very good chance that the Sir Dorabji Tata Trust, and perhaps also the Sir Ratan Tata Trust, will respond. After all, the advancement of science is one of the fundamental objects with which most of the Tata Trusts were founded, and they have already rendered useful service in that field. If they are shown that they can give still more valuable help in a new way, I am quite sure that they will give it their most serious consideration". Thus encouraged by Mr. J. R. D. Tata, Homi Bhabha wrote a letter dated 12th March 1944, to Sir Sorab D. Saklatvala, Chairman of the Sir Dorabji Tata Trust, in which he outlined his proposal for the setting up of an Institute of Fundamental Research in Bombay. The letter is a remarkably prophetic letter and contains many of the basic guidelines which defined the way in which Homi Bhabha and the Tata Institute of Fundamental Research functioned later. For example, the letter contained the sentence:

> *"Moreover, when nuclear energy has been successfully applied for power production, in say a couple of decades from now, India will not have to look abroad for its experts but will find them ready at hand".*

This was written 18 months before the first atom bomb was dropped on Hiroshima in August 1945, by one sitting in Bangalore, with only the knowledge that nuclear fission had been discovered. It also emphasised Homi Bhabha's philosophy that, by planning and foresight, the country could train its own experts for the tasks of development, to have them ready to undertake these tasks as and when they did arise, and it was important for the nation to find strength within itself rather than develop an attitude of weak-kneed dependence on others.

Location of the Institute in Bombay

One of the reasons for locating the Institute in Bombay was the circumstance that the Director of Public Instruction of the Government of Bombay had approached Homi Bhabha to accept a chair of physics at the Royal Institute of Science, Bombay. Since the Sir Dorabji Tata Trust had already accepted Homi Bhabha's proposal for the establishment of a new Institute, he suggested to the Government of Bombay that the money which they proposed to spend on the creation of a chair for him and on equipment, would more effectively be used if they co-operated with the Sir Dorabji Tata Trust in a joint venture.

Founding of the Institute: June 1945

Thus it came about that the Institute was founded jointly by the Sir Dorabji Tata Trust and the Government of Bombay in 1945; the provisional Council of Management consisting of representatives from the two bodies held its first meeting on 18th May 1945, when the budget proposals for the year 1945-46 were passed, involving a total expenditure of Rs. 80,000/-. At this point it would be appropriate to place on record the important role played by Prof. Rustom D. Choksi, on the one hand in advising Homi Bhabha and on the other



Fig. 5—Professor Rustom D. Choksi, Member of the Council since 1949.

in dealing with various aspects relating to the setting up of the Institute on behalf of the Sir Dorabji Tata Trust. Prof. Choksi has been a Member of the Council of Management since 1949 and has throughout been a wise counsellor and advisor to the Institute.

Early History since its Foundation

Kenilworth

The Institute may be considered to have commenced its work on 1st June, 1945, at the Indian Institute of Science, Bangalore, in the accommodation then belonging to the Cosmic Ray Research Unit which was set up for Homi Bhabha. Its work continued there till it was gradually shifted to its temporary premises at Kenilworth, 53 Pedder Road, Bombay, in the course of the following year. These premises consisted of about 6,000 sq. ft. of space in one half of a bungalow;

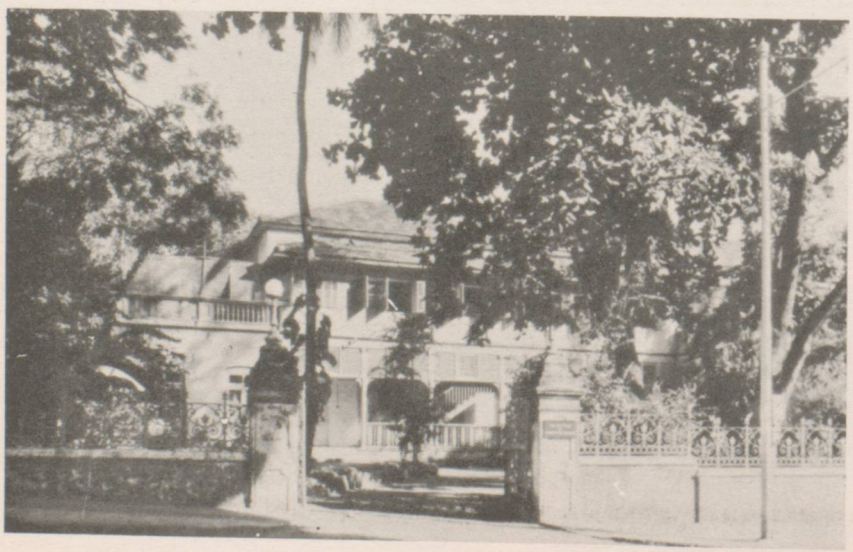


Fig. 6—Kenilworth, the first home of the Institute in Bombay.

it was in this bungalow that Homi Bhabha was born on 30th October, 1909. The temporary premises of the Institute at Pedder Road, Bombay, were formally declared open at an inaugural function on 19th December 1945 by Sir John Colville, Governor of Bombay. The equipment of the Cosmic Ray Research Unit at the Indian Institute of Science, Bangalore, was brought over with a special grant given by the Sir Dorabji Tata Trust.

Role of the Council of Scientific and Industrial Research and the Ministry of Natural Resources and Scientific Research

Role of the Government of India in the early Stages

In the first year, 1945-46, the Council of Scientific and Industrial Research (CSIR) sanctioned a grant of Rs. 10,000/-; this was for "Measurements on Cosmic Rays and ground experiments on Mesons". For the next year, CSIR, under the presidentship of Sir Ardeshir Dalal, and with the enthusiastic support of Dr. S. S. Bhatnagar, provided a block grant of Rs. 75,000/-, subject to the condition that adequate representation was given to CSIR on the Council of Management of the Institute; and thus in April 1947, Dr. S. S. Bhatnagar, FRS, took his seat on the Council of the Institute as the representative of CSIR. In 1946, CSIR appointed an Atomic Research Committee for promoting research in atomic energy. As the Institute was the place in India at which the largest amount of theoretical and experimental work in nuclear physics was being carried out at that time, CSIR, on the recommendation of the Atomic Research Committee, gave a special grant to the Institute in 1947-48 for training a team of scientists in the general techniques of nuclear physics, with special reference to high energy accelerators. In 1948, the Government of India in the Ministry of Natural Resources and Scientific Research entered the picture with a block grant of Rs. 1 lakh for 1948-1949; and over the period 1948-51, support by the Government of India to the Institute through this block grant was gradually increased.

Role of the Atomic Energy Commission

The Atomic Energy Commission of the Government of India was established in 1948. One of its immediate problems was the shortage of trained scientific personnel in its field. During the three years preceding the establishment of the Commission, the Institute had already collected and built up a small group of scientists trained in some of the special techniques of nuclear physics with the assistance of CSIR. It was therefore natural that the Commission should turn to the Institute for carrying out its own projects and for training further personnel for it. The Institute thus carried out a number of projects for the Atomic Energy Commission with joint teams of personnel belonging to the Institute and the Physics Division of the Atomic Energy Commission. The senior members of most of these teams belonged to the Institute and were drawn from the original group built up at the Institute. This co-operation has steadily grown and forms the basis on which the Institute is supported today by the Government of India through the Department of Atomic Energy. The close link established between

the activities of the Institute and the Atomic Energy Commission, and the satisfactory manner in which these services were rendered by the Institute moved the Atomic Energy Commission, on the initiative of Dr. S. S. Bhatnagar, at its 27th meeting on the 22nd and 23rd April 1953, to record the following: "The Commission noted that it had recognised the Tata Institute of Fundamental Research as the only laboratory of the Commission for fundamental research in atomic science. In view of this decision, the Commission would not set up another laboratory of its own for fundamental research in atomic physics."

The temporary premises of the Institute in Kenilworth on Pedder Road, having a usable floor space of some 6,000 sq. ft. were entirely inadequate for these expanded activities. Consequently, a floor space of some 35,000 sq. ft.

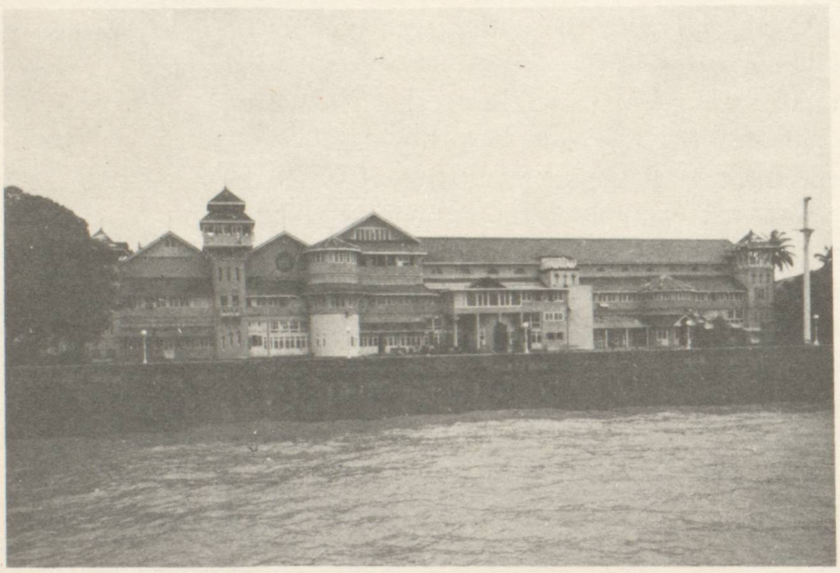


Fig. 7 — Old Yacht Club Building seen from the Bombay harbour. The Institute was housed here from 1949 to 1961.

Permanent buildings of the Institute

was leased in the premises vacated by the Royal Bombay Yacht Club at Apollo Pier Road; and in September 1949, the Institute's activities were moved to these new temporary premises. The Commission also leased space for its work in the same building.

For a period of approximately a decade, throughout the 1950s, the Institute continued with its activities at the Old Yacht Club building. Even within the first few years it became clear that shortage of space would be the main restricting factor in the growth of the Institute. Accordingly, the Council sought for a suitable site for putting up the permanent buildings of the Institute. A valuable plot in the new reclamation area of Bombay was generously offered by the Government of Bombay; this offer was not accepted since it was clear from the rapid expansion of the Institute that this area would be inadequate. Finally, a suitable plot of land was located in Block VIII of the Colaba Reclamation. This land was in the possession of the Ministry of Defence; and accordingly, a request was made to the Government of India to transfer this to the Institute. Whilst the Government of India was unable to spare the full area asked for, it generously



Fig. 8 — Marble stairs leading to the Library from the entrance lobby of the Institute.

gave the Institute 15 acres in Block VIII of a most suitable site adjoining the sea. This was a result of the great personal interest that Prime Minister Jawaharlal Nehru took in this matter, the tireless efforts of Sir S. S. Bhatnagar and the co-operation extended by Sardar Baldev Singh, Minister of Defence.

In planning the buildings of the Institute, the Council took the view that the latest and the best ideas in laboratory design should be incorporated; accordingly, a noted firm of architects in the USA, M/s. Holabird and Root of Chicago were commissioned to design these buildings. This firm, and particularly the principal architect, Mr. Helmuth Bartsch, who took a deep personal interest in this project, did a truly magnificent piece of work; the overall architectural concepts, involving the balanced juxtaposition of the masses of the buildings, and changing vistas, constantly arouses the admiration of those privileged to work in it, as well as

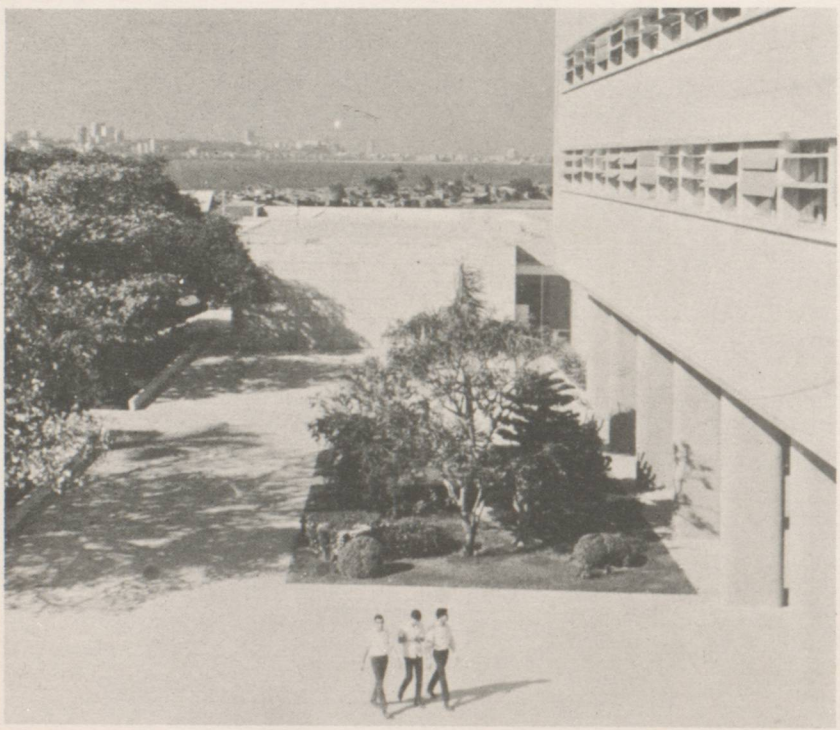


Fig. 9— The terrace garden in the colonnade area.

those who have occasion to visit and to see these buildings. In order to minimise the dollar payments which would have to be made to a foreign firm, and in order to utilise the services of Indian architects to the maximum extent possible, M/s. Master, Sathe and Bhuta, who had designed and built the National Physical and Chemical Laboratories of the CSIR, were appointed as executing architects; Shri Kanvinde, architect of CSIR, was also associated with the early stages of the building project. The foundation stone of the New Buildings was laid by Prime Minister Jawaharlal Nehru on January 1, 1954.

It may be interesting to recall that in putting up these buildings, several pioneering efforts were made which have been of permanent benefit to the country in the area of building construction; for example, aluminium companies in India

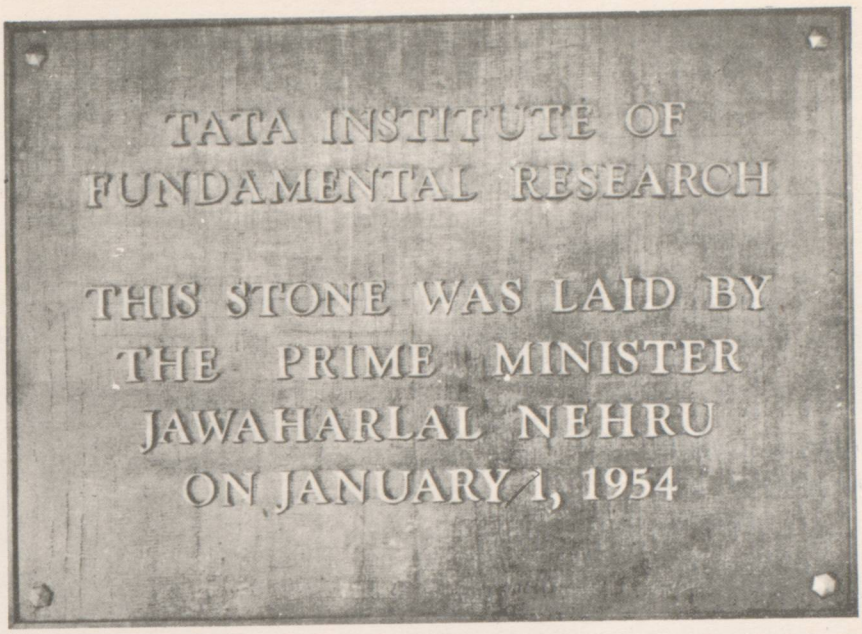


Fig. 10—Plaque to commemorate the laying of the foundation stone of the new buildings of the Institute by Jawaharlal Nehru, Prime Minister of India, on January 1, 1954.

were induced to extrude special large sections for windows and doors in a rustless alloy resistant to corrosion by the warm sea air; the welding and fabricating of these windows, the use of adjustable louvres for sun control and such other features were carried out for the first time in India; these are only examples in a whole list of such items that are now common in Indian buildings as a result of these efforts.

Special mention should be made of the principal contractors, M/s. Shapoorji Pallonji and Co. Pvt. Ltd., who carried out a magnificent job of building construction, both in putting up the main laboratory and office areas and later the

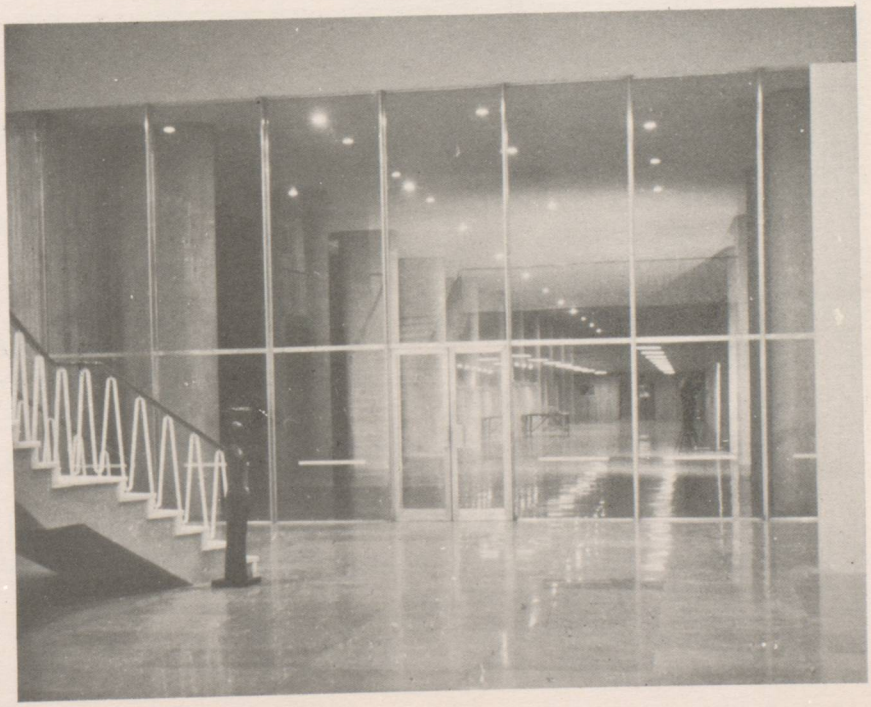


Fig. 11—Colonnade of the Institute viewed from the main lobby.

Homi Bhabha Auditorium and Museum complex. It is important to stress that the task of putting up these buildings was not just given out as a standard job; it was an effort in which senior members of the Institute on the academic and administrative side, as well as the members of the Architecture and Civil Engineering Division of the Bhabha Atomic Research Centre participated whole-heartedly; as a result, the quality of the building, particularly as can be seen after a decade of use, is very much higher than normally the case at the same cost per square foot of construction. It should be particularly stressed that Homi Bhabha spent a great deal of his time and energy in the detailed planning and aesthetics.

Research work in hutments for half a decade

When this particular site was taken over by the Institute in 1954, it had on it a large number of hutments and barracks, as also gun emplacements; it had been a military site and was a location for coastal gun batteries. The hutments were renovated and fitted up as laboratories; and active research was conducted in these for half a decade so as to ensure that the growth of the Institute was not restricted through lack of space. Homi Bhabha has remarked:

> *"work has inevitably been built up first and the permanent buildings have come afterwards".*



Fig. 12— Military hutments on the land acquired (1953) for putting up the permanent buildings of the Institute at Colaba; these were converted into laboratory blocks and used until the new buildings were ready. The control system of the 1 MW swimming pool reactor APSARA at BARC was fabricated in one of these hutments.

Even when the New Buildings were under construction, and only the basement was just ready in 1956, the balloon production group was moved into it; the long basement was ideal for placing the very long tables needed for the production of large volume polyethylene balloons. And as the buildings became ready, group after group moved in. The buildings were formally inaugurated by Prime Minister Jawaharlal Nehru on January 15, 1962; by then they were already fully occupied.

Tripartite Agreement

By 1955, it had become clear that the Government of India's interest in the work of the Institute was of a permanent nature. Considering it "to be in the interests of the country to maintain a high level academic institution where study, search for knowledge and scientific research shall be pursued for the purpose of increasing man's knowledge of nature without considerations of practical utility", the Government of India signed a new Tripartite Agreement with the Government of Bombay and the Sir Dorabji Tata Trust, as a result of which the Institute came to be recognised as the National Centre of the Government of India for advanced study and fundamental research in nuclear science and mathematics.

Prior to 1956, the administration and management of the Institute vested in a Council consisting of one representative of the Government of Bombay, two representatives of the Sir Dorabji Tata Trust, one representative of the Government of India and the Director of the Institute. The Tripartite Agreement envisaged extensive financial support from the Government of India and correspondingly a greater and more permanent representation for it on the Council of Management.

The Tripartite Agreement came into force with effect from April 1, 1956. Under the Agreement each of the parties covenanted to pay a minimum block grant-in-aid towards the maintenance of the Institute and also to pay a non-recurring specified grant-in-aid towards the cost of buildings and equipment of the Institute. These are the minimum grants provided under the Tripartite Agreement. The annual block grants-in-aid are fixed by mutual agreement between the parties in the light of the existing conditions. Since the Government of Bombay (now Maharashtra) and the Sir Dorabji Tata Trust were not in a position to enhance their financial contributions above the minimum laid down in the Tripartite Agreement, the Government of India has assumed the entire responsibility to provide the additional funds needed by the Institute. Today, 99% of the expenditure of the Institute is borne by the Government of India. The Institute comes under the administrative purview of the Department of Atomic Energy through which these grants are channelled.

Homi Bhabha strongly believed that:

> *"financial support from Government need not, however, entail government control".*

In this he quoted Professor A. V. Hill, FRS, Senior Secretary of the Royal Society, who in his lecture to the Indian Science Congress at Delhi had stated: "many of these independent scientific institutions in Great Britain now-a-days are receiving substantial state support: but nearly always, when this is done, a buffer of some kind is interposed to prevent Government support from becoming Government control". Accordingly, when the Tripartite Agreement was drawn up, importance was attached to the necessity of introducing financial procedures that are consistent with those followed in the Universities and high level scientific institutions abroad and which do not have the rigidity of government procedures. In particular, the Institute accounts are audited by a firm of commercial auditors,

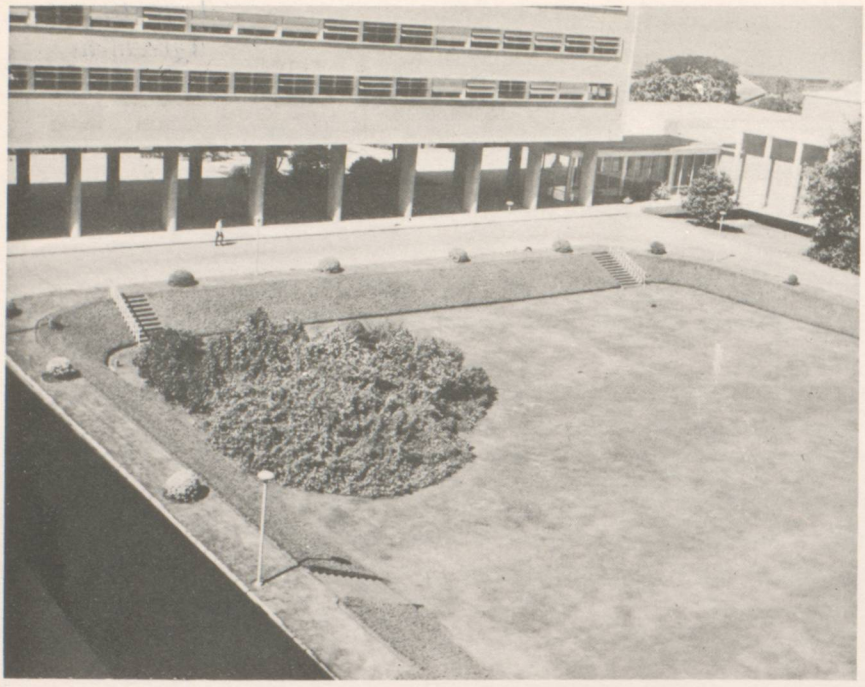


Fig. 13— East lawn with the colonnade in the background.



Fig. 14— View of the East Lawn showing the road leading to the front gate of the Institute.

who answer a specific set of questions laid down by Government to ensure that the grants are utilised for the purposes for which they were given.

Council of Management

Under the Tripartite Agreement the Institute is run by a Council of Management consisting of three persons appointed by the Government of India, one person appointed by the Government of Bombay and two persons appointed by the Trustees of the Sir Dorabji Tata Trust; the Director of the Institute is an ex-officio member of the Council. A list of those who have served on the Council of Management of the Institute is given elsewhere in this Report. The Institute has been fortunate in the quality of the members it has thus far had on its Council. They have throughout displayed a sense of vision, imagination, and a keen sense of awareness of the needs of scientific research.

Homi Bhabha remarked in January 1966, in the last speech he gave before his death:

> *"the type of administration required for the growth of science and technology is quite different from the type of administration required for the operation of industrial enterprises, and both of these are again quite different from the type of administration required of such matters as the preservation of law and order, administration of justice, finance, and so on".*



Fig. 15 — View of the Council Room of the Institute.

The Council of the Institute has fully appreciated this and provided it with an administrative structure of the type needed for growing science.

The immoveable properties and funds of the Institute other than those vested in the Council of Management are vested in a Board of Trustees on which each of the 3 parties to the Tripartite Agreement are equally represented.

Rules and Byelaws: Management of the Institute

On the basis of the Tripartite Agreement, new Rules and Bye-laws were framed for the general administration and management of the Institute. These provided for large scale delegation of powers at all levels. It is gratifying that

the Model Constitution which was prescribed by the Scientific Advisory Committee to the Cabinet for scientific institutions in the country in general was based on the Rules and Bye-laws of this Institute.

The Council of Management of the Institute deals with policy aspects which have long range implications or involve large financial outlays; in particular, it normally considers the annual budget, appointments at senior levels, new programmes involving a large initial/recurring financial outlay, matters relating to scales of pay, etc. Within the framework of policy laid down by the Council, the Director has full authority to run the Institute as he considers appropriate.

The Director is assisted by two Faculties, one for the School of Mathematics and the other for the School of Physics; staff of the rank of Associate Professor and above are members of either of the two Faculties as appropriate. Additionally, there are a large number of Committees to deal with various general facilities of the Institute, such as the Library, Engineering Services, (including the workshop, glassblowing section, technical maintenance, etc.), Stores and Purchase; as also Committees appointed by the two Faculties to deal with matters which come under their purview. There is a constant rotation of membership of these Committees, so that the administrative load on individual scientists is reduced; and at the same time, there is a greater sense of participation at various levels in the running of aspects of the Institute which directly concern the scientists and their programmes of work. Each Faculty Member is fully authorised to incur expenditure upto the limit of the budget sanctioned for his group, whether for capital or for stores, in the manner he considers appropriate, without reference to the Faculty, Director or Council. Even more important than the formal aspects just discussed are the continuing informal contacts and discussions characteristic of the existence of a genuine scientific community.



Fig. 16 — General Lounge on the ground floor adjoining the canteen.

Relationships with the Atomic Energy Commission

When Homi Bhabha set up the Tata Institute of Fundamental Research, he already had in mind plans for growing the Indian atomic energy programme. The Atomic Energy Commission was set up in 1948 and the Department of Atomic Energy in 1954. Work on the thorium plant at Trombay was started in 1953 and on the 1 MW Swimming Pool Reactor APSARA in 1955; and gradually the whole complex of the Bhabha Atomic Research Centre grew. Homi Bhabha headed all of these until his death in 1966. The relationships between the Institute and the Atomic Energy Commission are perhaps best expressed in the words of Homi Bhabha as in the paragraphs below:

"In the field of research, an Atomic Energy Commission must promote two kinds of activity: (1) research of a semi-technical or technical nature aimed at solving the problems which arise in the construction and design of atomic reactors and in the processing of materials connected therewith; and (2) fundamental research in all aspects of atomic science without any reference to its immediate utility.

(1) should be carried out mainly in establishments owned solely by the Commission, though individual problems may be farmed out to various laboratories. . . . An atomic reactor should only be set up, at least under present circumstances, in establishments owned solely by the Commission.

On the other hand, fundamental research should be sponsored by the Commission mainly in institutions other than its own, as for example in the universities and research institutes, where a free intellectual and academic atmosphere prevails. Certain projects of this type, however, are too big to be conveniently carried out in the normal laboratory of a university. . . .

The Tata Institute of Fundamental Research fulfils precisely this role of being an Institute at which the Commission can carry out its large scale projects of fundamental research. Fundamental research thrives best in an atmosphere that is free, permitting an unrestricted exchange of ideas. An institution for fundamental research should be open to all scientists of eminence, whatever the country to which they belong, and should be unfettered by the secrecy regulations required in commercial or strategic establishments. Had the Institute not existed, the Indian Atomic Energy Commission would have been compelled in time to create such an institution where fundamental research in atomic science could be carried out in a free academic atmosphere on a scale larger than is convenient in a university laboratory."

(Homi Bhabha—1954)

"The Atomic Energy Commission of the Government of India was first established in 1948, and one of its immediate problems was the shortage of trained scientific personnel in its field. It was therefore natural that the Commission should turn to the Institute for training personnel for its work, and for carrying out some of its own major projects. These early projects were carried out by joint teams belonging to the Institute and to the Physics Division of the Atomic Energy Commission, which was then housed in the Institute's premises and looked after administratively by the Institute. The Commission, on its part, gave substantial help to the Institute by providing funds for increasing its activities and for specialised equipment for nuclear research.

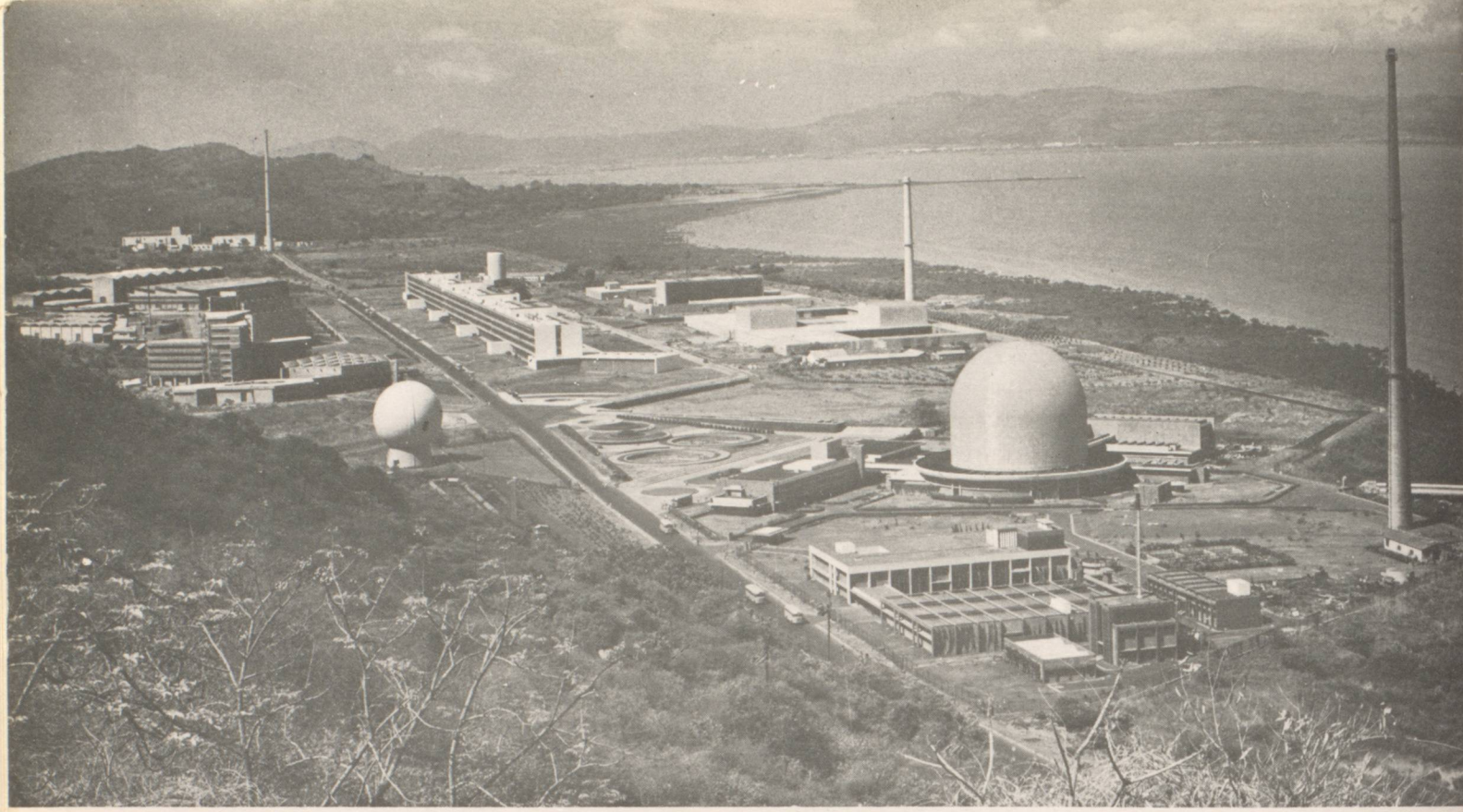


Fig. 17 — The Bhabha Atomic Research Centre at Trombay, Bombay.

One of the first activities undertaken by the Institute for the Commission was the setting up of a small electronics group to design and build the electronic instruments without which atomic energy work is impossible. This group was the nucleus from which grew the present Electronics Division of the Atomic Energy Establishment at Trombay with a staff of over 560 people, and which is now producing not only most of the electronics instrumentation used at Trombay, including the control systems of reactors, but also that which will be used all over the country in agricultural, biological, industrial, and medical work with radioactive materials. The Institute has given some 46 members of its scientific staff to man various divisions of the Atomic Energy Establishment at Trombay, to mention only two, Shri A. S. Rao, Head of the Electronics and Health Physics Group, and Dr. R. Ramanna, Head of the Physics Group. There was a time when no less than 175 members of the staff of the Trombay Establishment were looked after by the Institute. It is also appropriate to recall on this occasion that the control system of APSARA, the first reactor in Asia, was built under the auspices of this Institute in a war time hutment on this very site, and many parts of the reactor in the Institute's workshop. It is not an exaggeration to say that this Institute was the cradle of our atomic energy programme, and if the Atomic Energy Establishment at Trombay has been able to develop so fast, it is due to the assisted take-off which was given to it by the Institute in the early stages of its development. It is equally true to say that the Institute could not have developed to its present size and importance but for the support it has received from the Government of India."

(Homi Bhabha—15 Jan. 1962)

In addition to the above organic relationships outlined by Homi Bhabha, it would be useful to record some of the individual activities characteristic of the strong bonds that exist between the Institute and the Atomic Energy Commission:

(i) The Electronics Group and Technical Physics Division of the Bhabha Atomic Research Centre had their origins in work initiated at the Institute.

(ii) The 1 MeV cascade generator of the Institute has been used extensively as a source of pulsed neutrons for studying the slowing down of neutrons in various assemblies.

(iii) The mass production of Boron trifluoride neutron counters and of plastic scintillators by groups from BARC was carried out at the Institute.

(iv) Considerable time on the CDC 3600-160A computer system at the Institute is availed of by institutions under the administrative purview of the Department of Atomic Energy: Bhabha Atomic Research Centre, Power Projects Engineering Division, individual Power projects, and groups concerned with programmes in space science and technology.

(v) The Computer Group of the Institute and the Computer Division of the Electronics Corporation of India at Hyderabad are working together on the design and manufacture of a family of versatile real-time computers, to meet, through indigenous production, the demands for small and medium range computation and for on-line applications.

(vi) Staff from the Institute have carried a considerable part of the teaching load of the Training School operated by the Bhabha Atomic Research Centre since 1957.

(vii) Liquid helium from the Institute plant is regularly supplied for experimental work at Trombay.

(viii) The Institute uses appreciably the facilities at the APSARA and CIRUS reactors and the Van-de-Graaff accelerator at Trombay.

(ix) The Institute has undertaken a major project connected with the design and fabrication of radars required for the space programme.

(x) There are regular administrative arrangements for the transfer of staff between the various institutions that come under the purview of the Department of Atomic Energy, including the Tata Institute of Fundamental Research.

These and many other such aspects are indicative of the strong interactive relationships that exist between the Institute and the atomic energy and space programmes of the country.

Subjects of Research and Study

The work of the Institute has, up to now, been carried on in two Schools: a School of Mathematics and a School of Physics. *In the paragraphs below, a brief account is given of the work currently in progress in the Institute.*

SCHOOL OF MATHEMATICS

The School of Mathematics was organised with a view to building up a body of competent scientists, who could carry out mathematical research at the highest level in fields of current interest. For this purpose, a few talented young persons are selected each year and prepared for mathematical work, by means of a carefully planned programme of intensive training, meant to bridge the gap between college mathematics and creative work. The activities of the School centre round lectures and seminars conducted by members of the School, supplemented by lectures given by eminent visiting mathematicians from all over the world. The group is engaged in active research in almost every major branch of pure mathematics—classical and functional analysis, differential equations, function theory, differential geometry, algebraic geometry, Lie groups and Lie algebras, commutative and homological algebra, differential and algebraic topology, analytic and algebraic number theory, etc.; substantial contributions have been made to these subjects by members of the School. The School has organized international symposia from time to time, four upto now, under the co-sponsorship of the International Mathematical Union: on Zeta-functions (1956); Function theory (1960); Differential Analysis (1964); and Algebraic Geometry (1968). The proceedings of these symposia have been published.

SCHOOL OF PHYSICS

Work in the School of Physics covers both theoretical and experimental investigations. In addition to what might be termed as pure physics, work in progress includes aspects of biology, chemistry, geophysics, astrophysics, computer sciences, solid state electronics and microwave engineering. These are detailed in the sections below:

High Energy Physics and Particle Physics

Theoretical Physics

The strong, electromagnetic and weak interactions of elementary particles and their symmetry properties are being studied, using the methods of field-theory and group theory and the S-matrix approach. Phenomenological approaches to high energy physics are also being pursued.

Nuclear Physics

Problems of nuclear structure are being studied, both on the basis of various nuclear models, as well as in terms of basic nucleon-nucleon inter-

actions using the techniques of many-body theory. Work is also being carried out on the statistical properties of nuclear levels, and on nuclear reactions.

Solid State Physics

The interest has mainly been in the theoretical aspects of non-linear optics, Raman scattering, positron annihilation, phase transitions, magnetism, band structure, superconductivity and liquid helium.

Experimental Programmes

Experimental work is being carried out in the following areas: (i) Cosmic Ray Physics; (ii) High Energy Physics; (iii) Geophysics; (iv) Radio Astronomy and Astrophysics; (v) Nuclear Physics; (vi) Chemical Physics; (vii) Solid State Physics; (viii) Computer Sciences and Technology; (ix) Instrumentation I —Solid State Electronics; (x) Instrumentation II—Microwave Engineering; (xi) Molecular Biology; and (xii) Basic Dental Research.

Cosmic Ray Physics

Studies at Balloon Altitudes: There is a continuing programme of cosmic ray studies at high altitudes based on the balloon facility developed by the Institute, which is described in a later section. These studies are being carried out with specially designed nuclear emulsion assemblies as also electronic counter assemblies, that are kept floating on balloons, for extended periods of time, close to the top of the atmosphere. The current emphasis is on: the spectrum of high energy electrons; background X-rays and gamma rays; X-rays and gamma rays from discrete sources such as pulsars, supernova remnants, galactic nucleus etc.; neutrons and gamma rays from the sun; and the chemical and isotopic composition of the primary radiation. Examples of the equipment carried up on these flights are: large-aperture magnetic spectrograph incorporating wide gap spark chambers, scintillation counters and nuclear emulsions, for the accurate measurement of the momenta of charged particles in the primary cosmic ray beam up to energies of 10^{11}eV; X-ray telescopes mounted on orientation platforms which enable long exposure to specific X-ray sources etc. Time variations in the intensity and spectra of some of the X-ray sources are being investigated; and in the case of certain individual sources simultaneous observations are being made in the X-ray, radio and optical regions of the electromagnetic spectrum.

Extensive Air Showers: Extensive Air Showers of the cosmic radiation are being studied at two locations, viz. Ooty (altitude 2.2 km) and at Kolar where underground levels in the gold mines upto a maximum depth of 10,000 feet below ground are available. In the Ooty array the shower size and core position is obtained from large number of scintillators spread out within a circle of radius 40 m; various other detectors have been used at appropriate locations from time to time to suit the observational needs; they have included:

shielded GM counter trays, Total Absorption Spectrometer, neutron counter assemblies, large multiplate cloud chamber etc. The detailed structural properties of air showers and the inter-relations between the various components have been under investigation. At Kolar a surface air-shower array is operated in conjunction with large-area particle-detectors, like scintillation and Cerenkov counters, at various depths underground where only the ultra high energy muons can reach. These experiments have a bearing on the characteristics of ultra high energy interactions, and on the chemical composition and spectrum of cosmic radiation at energies beyond 10^{14} eV.

Underground Experiments on Muons and Neutrinos: Systematic investigations on the variation of muon intensity with depth and on the angular distribution of muons at various depths are being carried out in the Kolar Gold Fields using detector systems of large area consisting of scintillators, neon flash tube arrays as visual detectors and absorber layers of iron or lead. The observations made have a bearing on the electromagnetic and nuclear interaction characteristics of muons at very high energies, on the manner of production of high energy muons, and on the nature of the primary spectrum in the energy range above 10^{12} eV. These experiments are being carried out in collaboration with the Osaka City University, Japan.

Several specially designed large area telescopes, incorporating neon flash tubes and scintillators, were operated at a depth of 7,600 ft. below the earth's surface for several years for the detection of muons produced in the interactions of natural neutrinos. These experiments, involving neutrinos of much higher energy than are available at the accelerators, have a bearing on the character of weak interactions, and on such aspects as the production of intermediate bosons etc. This experiment was carried out in collaboration with the Osaka City University, Japan and the University of Durham, U.K.

Theoretical and Interpretative Studies: Theoretical and interpretative studies are being carried out in various areas of what could be termed cosmic ray astrophysics: on aspects relating to the origin and propagation of cosmic rays, in relating information obtained through studies of high energy electrons with radio astronomical observations, models of pulsars etc.

High Energy Physics

Current work in high energy physics is based on the analysis of photographs taken with bubble chambers at the high energy particle accelerators. A new facility capable of processing 100,000 events per year has been set up; this programme depends heavily on the excellent computing facilities available at the Institute. Three measuring machines, in addition to the scanning machines, have been built at the Institute. A computer OLDAP, designed and built at the Institute is also being used as an on-line facility. With this set up it has become feasible for the Institute to participate actively, at a moderate cost, in

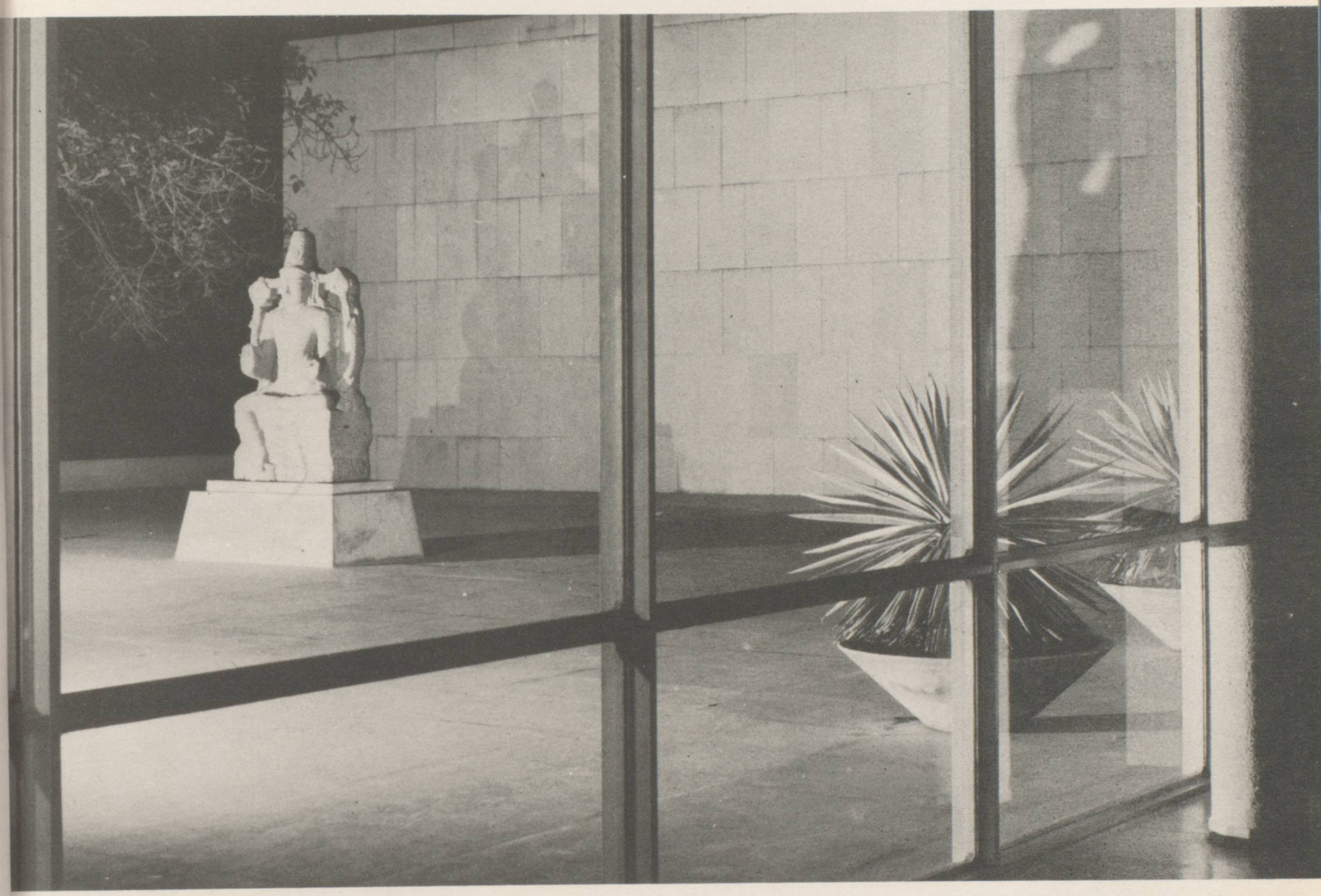


Fig. 18—Vishnu: on terrace adjacent to Homi Bhabha Auditorium. (From Village Sembianmadevi, Thanjavur District, Tamilnadu, South India: Chola Period Sculpture ca Tenth Century A.D.)



Fig. 19—The Apollo-11 Astronauts who visited the Institute on October 26, 1969 seen in the foyer of the Homi Bhabha Auditorium. (L to R Astronaut Michael Collins, Photographer, Shri H.N. Sethna, Director, BARC; U.S. Ambassador Kenneth Keating, Prof. M.G.K. Menon, Director, TIFR, Astronaut Neil Armstrong, Astronaut Edwin Aldrin, Dr. V.A. Sarabhai, Chairman, Atomic Energy Commission and Shri Prithi Singh, Chief of Protocol, Government of India). Investigations of lunar samples returned from the Apollo Missions are being carried out by the Geophysics Group of the Institute.

elementary particle physics based on the use of high energy accelerators. Two exposures have already been obtained. These are of a hydrogen-neon bubble chamber exposed to 3.5 GeV/c positive pi-mesons at Argonne National Laboratory (USA) and the other a hydrogen bubble chamber exposed to 0.72 GeV/c antiprotons at CERN, Geneva.

Geophysics

The natural distribution of a host of cosmic ray produced and naturally occurring radionuclides has been under study in diverse terrestrial materials with the help of specific micro-radiochemical and ultra low level counting techniques; many of these isotopes were discovered for the first time in these geophysical environments at the Institute. The observed distributions have been used to unfold the intricate nature of diverse geophysical processes: exchange of air across the tropopause; north-south mixing in the stratosphere and in the troposphere; rate of washout of aerosols from the troposphere; circulation of water within and between the principal oceans; rates of accumulation of biogenic silica-rich sediments; growth of manganese nodules, etc. A simple technique for the *in-situ* extraction of trace elements from large amounts of sea water (100-10000 tons), has been developed for the study of concentrations of radionuclides and stable trace elements present in sea water. A novel method has been developed and successfully employed to delineate the course of the south-west monsoon using natural radon (half-life—3.8 days) as a tracer.

Cosmogenic alterations i.e. isotopic changes and alterations in crystal structure (solid state damage) have been studied in extraterrestrial materials, (meteorites and lunar samples), due to the passage of charged particles. Important technical developments for the revealing of fossil tracks in silicate materials have been carried out. Results that are significant from the viewpoint of understanding the history of cosmic radiation as well as the history of formation and irradiation of solid objects in the solar system are as follows: prehistoric intensity of cosmic ray protons has been found to have remained constant during the last about 5m.y. within a factor of two; the long term average fluxes of both low energy solar cosmic ray particles and galactic iron group and heavier nuclei have been determined; there appears to be good evidence (from fossil track records) for the existence of transuranic Pu^{244} and elements of charge about 115 and mass about 300.

The remanent magnetisation of rocks collected from several geological horizons in India has been studied using sensitive magnetometers; the stability of the magnetic records has been examined. Interesting results have been obtained that bear on the drift of continents and reversals of the magnetic field through geological times. More recently, studies have been started on the basic properties of rocks as magnetic substances; several interesting results have been obtained in this area.

Radioastronomy and Astrophysics

A high resolution radio interferometer, working at 600 Mcs, for studies of the quiet as well as the active sun, has been in operation since 1965 at Kalyan near Bombay. It consists of 32 dishes, each 1.8m in diameter, of which 24 are placed in a 2,100 foot east-west array, and 8 in a 900 foot long north-south array. Observations with this array indicate that the solar corona has a temperature of 1.5×10^6 °K.

The main interest of the group now is in studies with the cylindrical radio telescope of large gathering power, (described in a later section), that has been set up at Ootacamund in South India. This radio telescope was designed primarily for lunar occultation studies of very distant radio galaxies lying at the edge of the Universe. Information on the detailed structure in these cases, with a resolution of a few seconds of arc, (which at present is available only for a few strong sources), is likely to be highly significant from the viewpoint of cosmology and for studying the origin and evolution of radio galaxies. The radio telescope is also currently being used for studies of pulsars. Other programmes for this instrument include: long base line interferometry, study of flare stars, radio emission from planets (particularly Jupiter), interplanetary scintillation, survey of weak radio sources in the southern hemisphere, determination of deuteron to hydrogen ratio, etc.

Work in Theoretical Astrophysics has covered: the equation of state valid for neutron stars, and the maximum mass of such a star; origin and variation of polarization of radio radiation from pulsars; properties of interstellar grains to explain the polarization of starlight; reformulation of the Wheeler-Feynman absorber theory of radiation; study of cool stars, etc.

Nuclear Physics

This group is mainly concerned with problems relating to the structure of nuclei. The experimental approach is through spectroscopic studies of beta and gamma-radiations emitted by radioactive isotopes and by analysing nuclear reactions induced in stable nuclei by high speed particles from accelerating machines.

Nuclear energy levels and their properties, (namely, spins and parties, life-times and magnetic moments, internal conversion of gamma-rays), are being studied using magnetic beta-ray spectrometers, scintillation gamma-ray spectrometers and solid state detectors. The 5.5 MeV Van de Graaff machine and the reactors at BARC are being used for nuclear reaction studies and for isotope production. Investigations are being carried out using the ion implantation technique and channeling of charged particles in single crystals. The circular polarization of gamma-rays and polarization correlations are also being studied.

The one million volt cascade generator of the Institute has been in use to study nuclear reactions with fast neutrons with a maximum energy of 16.75 MeV. Mono-energetic gamma-rays of energy upto 17.6 MeV are employed for photo-nuclear reaction studies. This accelerator is also used for studies of the slowing down of fast neutrons in various media and assemblies of materials—aspects that are of interest for the construction of reactors.

Chemical Physics

The Chemical Physics Group is basically interested in elucidating the electronic structure of molecules using modern theoretical and experimental techniques.

Work is being carried out on high resolution Nuclear Magnetic Resonance of organic compounds and transition metal complexes, and on the bulk magnetic susceptibility measurements of transition metal complexes and rare earth compounds. Mössbauer effect of Fe^{57} in several iron complexes at various temperatures is being studied. Electron Spin Resonance and Electronic Spin Lattice Relaxation in organic free radicals, inorganic complexes and doped single crystals are under investigation. Work is in progress on: electro-chemiluminescence; microwave spectroscopy of gases; valence bond and molecular orbital calculations of spin density distribution in free radicals. The conformational shape of biopolymers and its relation to biological activity is being investigated, both theoretically and experimentally.

Solid State Physics

Modern nuclear techniques, and radioactive nuclei as probes, are being used to investigate various aspects of solid state physics. Work is being carried out in the areas of the magnetic properties of solids, radiation effects in solids and defects in crystals.

Magnetic and electric interactions in metals, alloys and non-metals including Kondo systems are being investigated with wideline nuclear magnetic resonance spectrometers and resistivity techniques. Studies in Mössbauer spectrometry, positron annihilation, ultrasonic absorption and nuclear orientation at a very low (liquid helium) temperature are in progress to analyse various aspects of solid state physics. The facilities used for these investigations include a crystal growing capability, electron microscope and X-ray unit for structural studies, and the 3.5 MeV electron linear accelerator and a 3000-curie Co^{60} source for radiation damage studies.

Computer Sciences and Technology

Work in the area of computer sciences and technology is broadly divided into three parts: (i) Design, development and fabrication of computers and computer sub-systems; (ii) Software development; and (iii) Research in computation theory, logic, operations research, machine intelligence and perception. The Institute has been operating a CDC 3600-160A computer system as a national facility since 1964. OLDAP, an on-line data processor designed and fabricated by the Computer Group, is being used as a data acquisition facility for physicists in the Institute, particularly for the bubble chamber film analysis work.

The current areas of interest in hardware systems technology relate to on-line computers, on-line graphic consoles, thin film memory devices, and the fabrication of computer modules using multilayer printed circuit packaging techniques. In software development, a project to design and implement a small time-sharing system has been completed; and further work is envisaged in the study of languages for system programming and system design. Apart from this, program development is being undertaken to enable the use of a locally built cathode ray display console for computer-aided design of circuits and their layout.

Work is being carried out in mathematical logic, switching theory, theory of programming languages, and computation theory. Studies are being made in the field of system sciences and the application of operations research techniques for planning and management problems. In addition, there are active research projects in the following areas: question-answering systems, speech recognition and speech synthesis by machine, visual pattern recognition, simulation of human verbal behaviour and problem-solving by machine.

Instrumentation I—Solid State Electronics

The Solid State Electronics Group is primarily engaged in the study of the physics and technology of semiconductors and of thin films. Experimental facilities, (such as diffusion and alloying furnaces, epitaxial reactors, clean room, capacity discharge type welders, die bonding equipment, vacuum evaporation units, semi-automatic probing and mask alignment equipment), have been set up indigenously. Solid state devices like planar transistors and silicon-controlled rectifiers have been successfully fabricated and the properties of these devices investigated. The fabrication and study of integrated circuits, thin-film passive networks and solid state microwave devices viz. Schottky barrier diodes, Gunn diodes and Avalanche diodes, are in progress. Instruments are available for measuring diffusion depths, resistivity, and electron and hole mobility. The study of amorphous semi conductors has been taken up,

particularly as low cost memory elements. Work on microwave ICs is in progress and for this thick film technology is being developed.

Instrumentation II—Microwave Engineering

The Microwave Engineering group has been engaged in the design and production of microwave test equipment in the S-and X-band frequency ranges; signal generators, slotted lines, standing-wave ratiometers and frequency meters have been built and supplied to other users in the country. Noise sources, I.F. amplifiers and mixers for radar receiver testing have also been designed and built. Work on the fabrication of high power microwave tubes and on passive components such as transmit-receive cells is being carried out. Projects relating to the fabrication of several major systems needed for radars for the Indian space programmes have been taken up.

Molecular Biology

The Molecular Biology Group is concerned with the study and interpretation of basic biological processes at the molecular level, i.e. in terms of the structure and properties of molecules. Research is being carried out in the following areas: the process of genetic exchange during replication, recombination and transformation in bacteria; the synthesis and regulation of macromolecules such as RNA and proteins, with special emphasis on enzymes; mechanism of enzyme action and control of flux in multi-enzyme systems. Work has recently been undertaken also on differentiation and hormonal regulation in plant and animal cells.

The Molecular Biology Laboratory is specially equipped to study biological macromolecules. The available facilities include equipment for analytical and preparative ultracentrifugation, high voltage ionophoresis, amino acid analysis, isotopic methods, fluorometric and other photometric systems.

Basic Dental Research Unit

A large scale epidemiological study of oral cancer and precancerous conditions in the population of rural India in the states of Andhra Pradesh, Bihar, Gujarat, Kerala and Maharashtra has been carried out. About 10,000 cases were studied in each area; whenever lesions were encountered, a full clinical, histological and cytological examination was performed at the Institute's laboratory. A full record has been maintained using polaroid pictures. The CDC 3600 system at the Institute has been used for the final evaluation and correlation of oral cancer and precancer amongst the selected individuals in the above states; of interest is the correlation with existing habits and practices. Follow-up studies in the same areas are currently in progress.

Institute Activities that Constitute National Facilities

As a result of research that has been carried out, the Institute has developed competence of a unique character in several fields. Because of this it has been possible for the Institute to set up and to provide in these areas facilities which can be made use of by other scientists and institutions in the country. These national facilities are described in the sections below.

National Computation Centre

The National Computation Centre at the Institute is equipped with a Control Data Corporation 3600-160A computer system with a 32,768 word fast access core memory. The high speed peripheral equipment include: two punched card readers (which can read 1,200 cards per minute); two fast line printers (which can print 1,200 lines per minute); 12 magnetic tape units; a 16 million word disc-file; and a drum-type and a flat-bed Calcomp graph plotters. An on-line visual console with a light pen has been designed and built locally for use with this system.

The computer centre is completely maintained and operated by specially trained Institute staff members. Programming staff attached to this installation conduct periodic courses to instruct users in the utilization of the system. In addition, a considerable amount of system programming work has been done to improve the efficiency of the system. A limited time-sharing facility has been implemented with 4 on-line remote consoles.

The National Computation Centre has been in operation since June 1964. Currently the system is being operated for 168 hrs. a week on a job-shop basis. Over 180 different organizations throughout the country regularly make use of the computational facility. These include the Bhabha Atomic Research Centre, other units under the administrative purview of the Department of Atomic Energy, all the major Universities and Institutes of Technology, public and private sector industries, quasi-government organizations and national laboratories.

Balloon Facility at Hyderabad

Polyethylene balloons of volume up to 3 million cu. ft. are fabricated by the Institute; these are made both with imported polyethylene film as well as with film extruded in India under quality-controlled conditions, under supervision of Institute staff; the film is about 1 mil. in thickness; a large balloon is about 250 ft. in length. Ceiling altitudes up to 120,000 ft. have been obtained; gross lifts of about 1,000 kgms. have been handled. The balloons are filled with hydrogen. Tracking is done both optically as well as by radio; radio-command is used for in-flight operations and for cut-down of equipment on termination of the flight. Regular flight programmes are conducted from Hyderabad, which

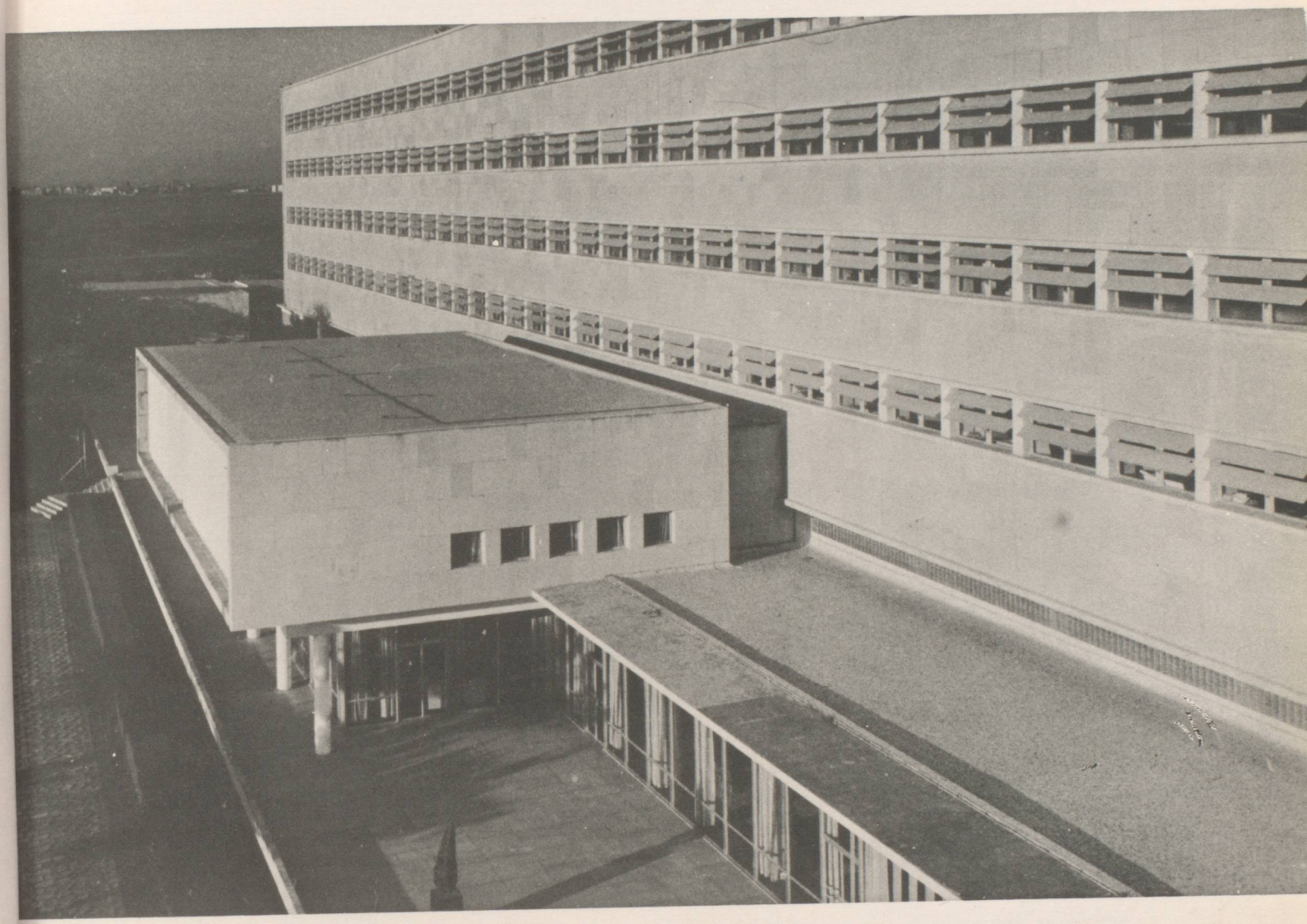


Fig. 20— View of the A block of the Institute with the Library (block to the left).

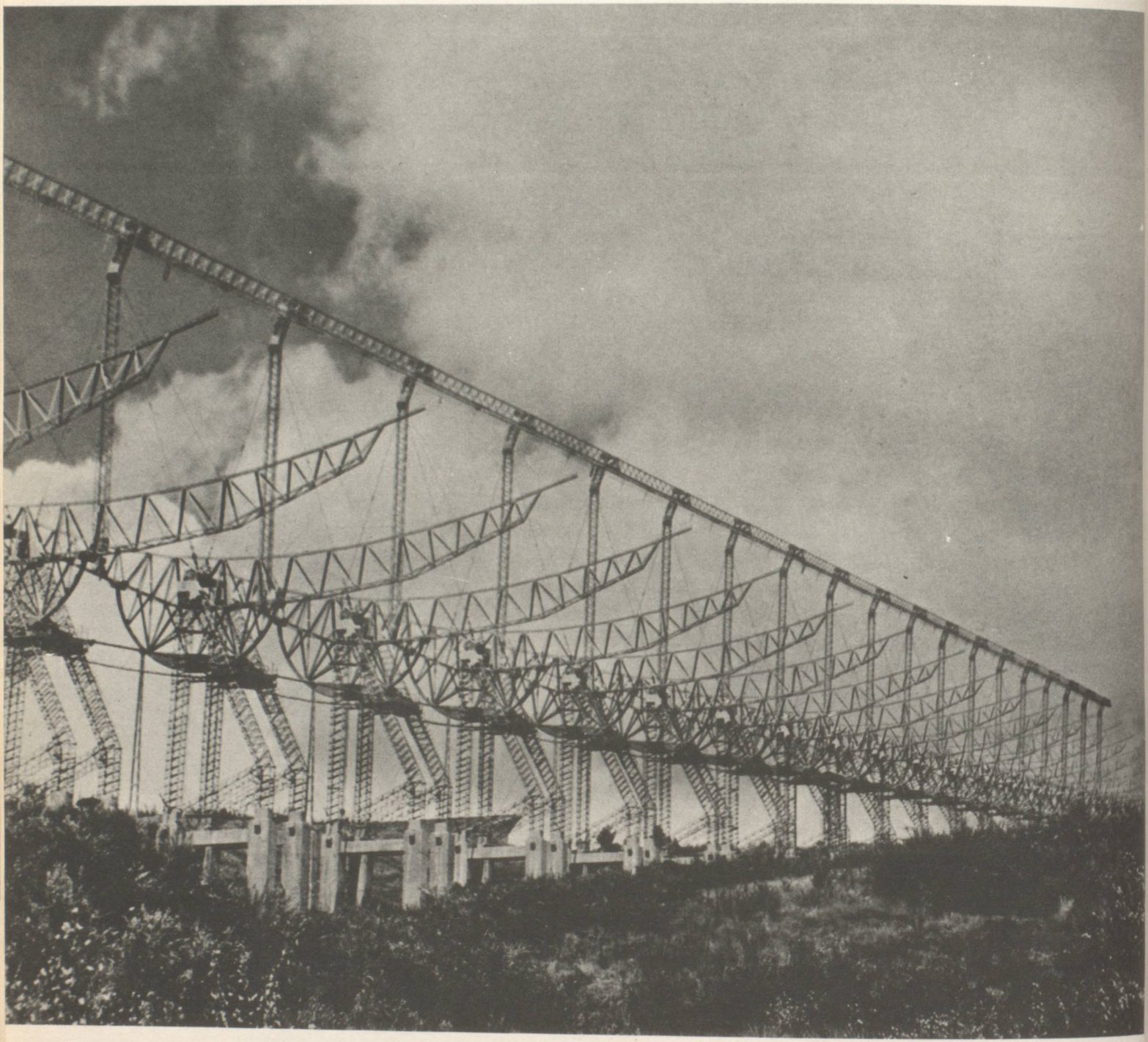


Fig. 21 — View of the large cylindrical radio telescope located at Ootacamund in the picturesque Nilgiri hills in South India.

is close to the geomagnetic equator, and has thus many unique advantages for work at balloon altitudes in the fields of cosmic-ray astrophysics and atmospheric research. Balloon flights over Hyderabad are also carried out by the Institute on behalf of other institutions in India. In addition, two major programmes were carried out from Hyderabad in 1961 and 1965 involving international collaboration. A regular national balloon facility has been set up at Hyderabad consisting of: a launch area, (from which balloons up to 10 million cubic feet in volume can be launched); laboratory for pre-flight work on equipment; hostel accommodation for those engaged on flight operations; hydrogen cylinder storage shed; and area for regular balloon production.

Radioastronomy Centre at Ootacamund

A large cylindrical radio telescope, 500 m long and 30 m wide, with its axis in the north-south direction, has been operational since February 1970 at Ootacamund. The telescope is placed on a slope with the northern end higher than the southern such that the latitude of the location, (Ootacamund), is exactly compensated for; thereby the axis of rotation of the telescope coincides with that of the earth. The instrument thus utilizes fully the location of India close to the geographic equator and provides very large gathering power, about 4 times that of the 250 foot dish at Jodrell Bank in England, at relatively low cost. The telescope can be mechanically rotated along its long axis in the east-west direction for 9½ hours per day. The beam of the telescope can be moved in the north-south direction by electrical phasing. The telescope operates in a fixed radio band of 324-329 MHz. It is proposed to add another frequency at about 100 MHz to it. The telescope which was designed and fabricated entirely indigenously is located in a 100 acre site in the picturesque Nilgiri Hills in South India. There is a hostel at the site for visiting scientists.

Radiocarbon Laboratory for Archaeology

The Radiocarbon Laboratory of the Institute was set up in 1961 as a national facility for archaeological work. To-date several hundred samples, deriving chiefly from sites in India, and representing the Chalcolithic, Harappan, Neolithic and the Gangetic cultures, have been dated; this represents the only large-scale, precise dating of archaeological samples in India; these dates have been of great help in establishing the chronology of these cultures in India. The errors in the estimation of a date are as low as + 100 years.

Laboratory for Hydrology

A Laboratory for Hydrology has been set up at the Institute as a national facility. Radioactive tritium, an isotope of hydrogen of mass 3, is used as a tracer for studying the characteristics of water reservoirs below the earth's surface. Other isotopes used for these studies are Si^{32} and C^{14}. The rates of recharge, the sizes of the underground reservoirs, and sources of water in the waterlogged areas are some examples of problems which are being studied in this laboratory. Collection of surface and subsurface water samples from several areas in India where such hydrological information is of vital importance was

begun in early 1961. Important results already obtained relate to the rather old character of most of the ground water reservoirs investigated thus far in Rajasthan, Gujarat and even in the Gangetic plain.

Supporting Facilities in the Institute

To support the research activities of the Institute the following general facilities are available: (i) Library; (ii) Workshop; (iii) Glass Shop and Precision Instruments Section; (iv) Cryogenic Facility; (v) Electron Microscope and X-ray Units; (vi) Irradiation Facility; (vii) Laboratory for Chemistry involving radioactive materials; and (viii) Lecture and Conference Facilities.

Library

The Institute has a well equipped library which functions on an "open access" system. The Library is open for 15½ hours on working days and for 8 hours on closed Saturdays, Sundays and holidays. The Library has about 25,000 books and 17,000 volumes of periodicals. In all, 825 periodicals are received by subscription and as gifts or by exchange.

Workshop

The Institute has a well equipped workshop for the design, fabrication, and where necessary the manufacture, of all mechanical equipment needed for its research activities, as well as for maintenance of the buildings and services (air conditioning, electricity, water supply, vehicles, etc.). The workshop works in two shifts; it also executes work orders from BARC for the development of special items of equipment, particularly those relating to the Technical Physics Division. The workshop has conducted an apprentice training school under which a large number of apprentices were given an intensive two-year course in workshop technology.

Glass shop

The Institute has a glass shop and precision instruments section in which highly skilled work is carried out in areas involving a combination of materials and needs: glass, metals, plastics, mechanical, electrical and electronic systems. In addition to meeting the routine requirements relating to glass and quartz apparatus, it has specialised in the fabrication of high vacuum stopcocks, ground-glass joints, glass-metal seals, dewar flasks, liquid helium cryostats of glass and quartz, etc. saving considerable imports. The shop carries out work for other scientific institutions in the country whenever necessary.

Cryogenic Facility

An Arthur D. Little Collins Helium Liquefier, (8 litres per hour), and a four-stage Phillips Nitrogen Plant, (30 litres per hour), are available for

cryogenic work. The group working at the plants also undertakes service and development work in cryogenics.

Electron Microscope and X-ray units

An electron microscope, (Phillips Type E-M200), capable of a resolution of 8 Å and magnification of 200,000 X, and a Siemens Crytalloflex-4 X-ray unit with back reflection camera and Debye-Scherrer powder camera are available for crystal structure studies, and for investigating biological and metallurgical specimens.

Irradiation Facility

For studies involving irradiation with electrons and gamma rays, the facilities available are a 3.5 McV electron linear accelerator, designed and fabricated at the Institute, which has been in operation for several years, and a 3000-curie Co^{60} radiation source which was recently installed.

Hot Laboratory

The hot laboratory is used for the storage of highly radioactive materials, for enforcing health physics procedures, and for the preparation and purification of different radioactive isotopes and sources; the latter work involves methods such as ion exchange, solvent extraction precipitation and electrodeposition. By donfining all storage and chemistry involving highly radioactive materials to the hot laboratory, it is feasible to reduce the chance of radioactive contamination in the main laboratory areas, and to carry out work in fields such as in isotope geophysics involving extremely low levels of activity.

Lecture and Conference Facilities

The Institute has 4 lecture halls and several seminar rooms in regular use. These have been used in the past for international and national conferences and symposia, held under the auspices of the International Council of Scientific Unions, International Mathematical Union and International Atomic Energy Agency on the one hand and the Department of Atomic Energy, Bhabha Atomic Research Centre and the Institute on the other.

Educational and Training Programmes

The Institute is "a constituent recognised institution" of the University of Bombay. In the letter dated 12th March, 1944, that Dr. Bhabha had written to Sir Sorab Saklatvala, Chairman of the Sir Dorabji Tata Trust, he had explicitly stated:

"The Institute would be affiliated to the Bombay University".

A member of the academic staff can register himself at the University of Bombay, (as also at many other Universities in India), for a post-graduate degree by research, and work under the guidance of a scientist in the Institute who has been recognised by that University as a teacher for that degree. The Institute is recognised by the University of Bombay for post-graduate research in mathematics, physics, (experimental and theoretical), and molecular biology; subjects to be added shortly for this purpose are: chemical physics and computer sciences.

Regular courses of lectures are conducted at the Institute, both in mathematics and physics, at pre-doctoral and post-doctoral levels; younger scientists at the Institute, particularly those registered for post-graduate degrees by research, have to take these courses. Most Indian Universities do not have any course requirements for the Ph.D. degree. The Institute has taken the viewpoint that even if this is so, it would like to ensure that those who obtain degrees through work carried out at the Institute have a broad high-level training which is so essential for scientific research today.

The main energies of the Institute have no doubt been directed towards creative research in the Schools of Mathematics and Physics, and in providing the necessary background for its staff engaged in this research, through colloquia, seminars, programmes of lectures given by staff of the Institute as well as by eminent scientists from abroad who are invited to spend extended periods of time at the Institute. In addition, the Institute is keenly alive to its responsibilities as a constituent institution of the Bombay University and the need to participate in the teaching programmes of the University for its students. The School of Mathematics actively collaborates with the University of Bombay in the latter's Centre for Advanced Training and Research in Mathematics; senior staff members of the School of Mathematics are deputed to the University for this purpose. The School of Physics participates in the teaching programme for the physics students of the Bombay University at the M.Sc. level. Members of the Institute serve on the Bombay University's Academic Council and Boards of Studies in Physics and Mathematics.

106 students have so far got their Ph.D. degrees and 27 their M.Sc. degrees, (in Mathematics and Physics), by working at the Institute. Currently 72 students are registered for the Ph.D. degree and 16 for the M.Sc. degree. 48 staff members are recognised guides for guiding students for the Ph.D. degree and 8 for the M.Sc. degree.

The School of Mathematics has conducted several Summer Schools intended mainly for University teachers. It organised Conferences on Mathematical Education in South-East Asia in 1956 and 1960.

Members of the School of Physics have been delivering courses of lectures and acting as tutors at the post-graduate Training School, (for physicists; chemists; mechanical, electrical, chemical and telecommunication engineers; and metallurgists), run by the Bhabha Atomic Research Centre in Bombay.

The Schools of Mathematics and Physics conduct each year several Summer Schools, in Bombay and outside Bombay, on different topics of current research interest. These Summer Schools are well attended by scientists from institutions from all over India.

Programme relating to science education in schools

Entirely on a voluntary basis, Institute scientists have been working on programmes for the improvement of science teaching at the school level. A start was made by organizing lectures and lecture demonstrations for students at a few local schools; this was arranged in co-operation with concerned teachers. Again, in association with the Bombay Municipal Corporation, Institute scientists have been participating in a teacher-training workshop, as well as in organizing an annual Inter-School Science Exhibition; 2 of the latter have been held so far, in February 1970 and February 1971, each involving about 50 schools. It is fully realised that improvements in the teaching of science at the school level have to be effected by the teachers themselves, and that research scientists, who are not experts in these areas, can only provide administrative support and scientific expertise; accordingly, monthly seminars have been arranged for school teachers to discuss teaching aids and teaching methodology with Institute scientists; as also monthly lecture demonstrations at the Institute for students; the latter have been very popular, and ways and means of using the Homi Bhabha Auditorium for this purpose are being explored in order to cater to much larger numbers. A regular teaching workshop on an annual basis for Municipal School Teachers has also been organized since 1970.

Publications

The Institute publishes, on a regular basis, books, pamphlets, lecture notes and proceedings of conferences, symposia and summer schools. These publications can be classified as follows:

(i)Lecture notes in Mathematics and in Physics; (87 volumes have been issued); (ii)Monographs in Mathematics and Physics; (2 volumes have been issued), (iii)Studies in Mathematics and Physics; (7 volumes have been issued); (iv)Mathematical Pamphlets; (4 pamphlets have been issued); (v) Books in the series 'Frontiers in Physics' published by W. A. Benjamin Inc., New York; (1 volume has been issued); (vi) The 1962 Inauguration Lecture Series; (4 volumes have been issued); (vii) Proceedings of Conferences and Symposia; (6 conference proceedings and 1 symposium proceeding have been issued).

The School of Mathematics was responsible for bringing out a facsimile edition in two volumes of the unpublished notebooks of Srinivasa Ramanujan.

In addition to the Lecture Notes, Studies in Mathematics and Monographs, the School of Mathematics has also brought out the lectures given at summer schools (intended mainly for university teachers and research scholars), thus meeting the need for low priced text books in the country on these subjects. So far the following four titles have been published as pamphlets: Riemann Surfaces (1963), Algebraic Topology (1964), Galois Theory (1965) and Algebraic Number Theory (1966).

Over 1,800 research papers have been published so far by Institute staff members in various scientific journals of repute.

Staff

The Institute has a total staff of over 1,400, of whom 350 are qualified scientists and engineers concerned with research and development. The growth of staff in various categories, (research and development personnel, supporting scientific and technical staff, and other staff), over the history of the Institute is shown in the accompanying figure. Significant changes that have occurred through the 1960s, as can be seen in the figure, are related to the setting up of the National Computation Centre, the setting up of the large Ooty Radio Telescope, and the taking on of several projects of national importance on the basis of contracts awarded to the Institute. For all of these tasks, there has been need for an appreciable number of staff in the supporting categories.

A staff member is normally appointed on probation for one year, after which he or she may be given continuing appointment up to the age of 58; extensions beyond this age are individually considered by the Council. All

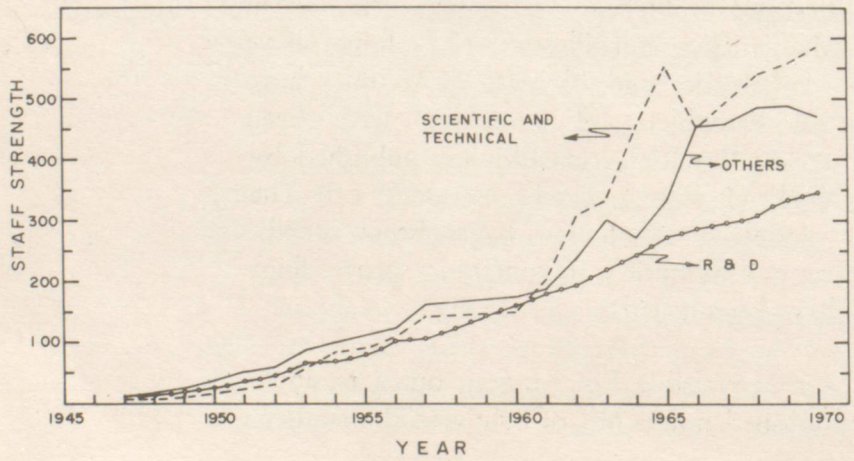


Fig. 22 — Growth of staff over the last 25 years plotted for three categories: Research and Development, Scientific and Technical and the Rest.

members of the academic staff engaged in research and development are, however, appointed on a contract, which is normally for a period of 5 years. There is at present no member of the academic staff who is on a regular continuing appointment.

No institution can expand on a continuing basis; and a major problem that every institution faces is that of saturation, and as a result, not being able to provide opportunities for fresh and vital inputs; there is also the problem of the biological ageing of the institution. As a partial solution to this problem, the Institute has reduced the in-take of staff who would continue on a semi-permanent basis even on a contract system, and instead has been providing a large number of visiting appointments at various levels for a year at a time, which would normally be for 3 years and for never more than 5 years. This results in a flow of scientists through the Institute; and out of these the Institute can always select a few outstanding persons for longer term appointments at the Institute.

Financial Aspects

The accompanying figure shows the actual expenditure for each year between 1945 and 1970 under the two major heads of the Institute's budget: salaries, and stores and equipment. These two heads constitute more than three quarters of the annual budget of the Institute, excluding non-recurring large individual

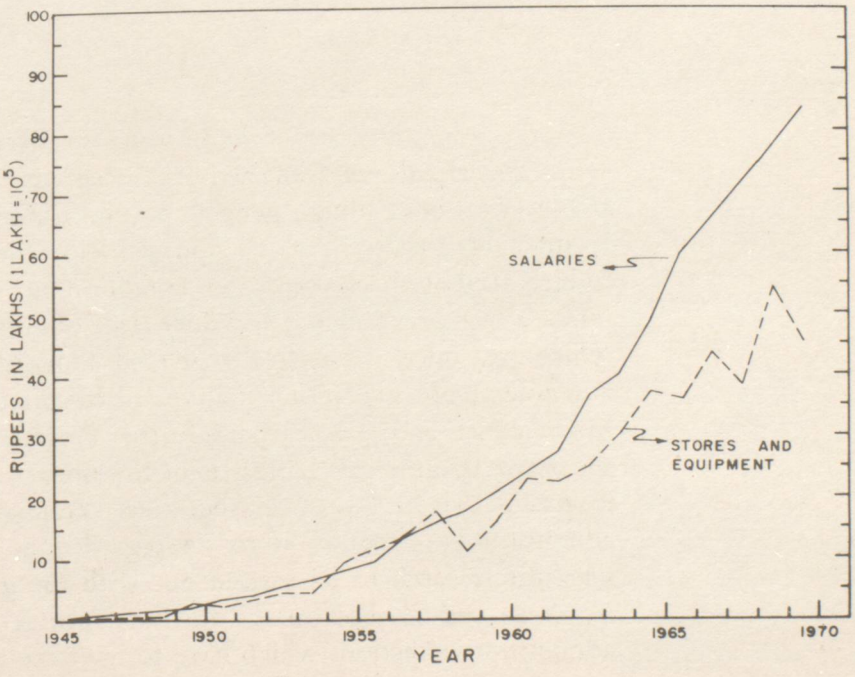


Fig. 23 — The Institute expenditure under "salaries" and "stores and equipment" over the last 25 years.

items of expenditure e.g. construction of buildings, purchase of major pieces of equipment such as computer systems etc.; in this figure expenditure on the purchase of the CDC 3600-160A computer system in 1964, and on considerably enlarging the system in 1969, as well as the expenditure on the cylindrical radio telescope project at Ootacamund, (1966-1970), have been excluded.

There has been rather strict control in the Institute on the growth of staff, particularly in the lower supporting and auxiliary categories. The basic philosophy has been that as much as possible of the budget should be available for actual research and development activities, and for the training of scientists.

A characteristic feature in the development of the Institute over the past few years has been the acceptance of contracts from several government agencies; these are additional to the funds received on an annual basis from the Government of India through the Department of Atomic Energy. These contracts have been of different types: in some cases they provide only for purchase of the stores and equipment needed for the Institute scientists to develop know-how concerning a piece of equipment or process; in other cases, the contracts also provide for the recruitment of project staff to execute the tasks assigned. Funds received on the basis of such contracts are now getting to be of a magnitude comparable to the annual budget of the Institute. Contracts accepted so far cover applied areas in computer sciences and technology, instrumentation, cancer survey, etc.

Administration

The administration of the Institute is carried out through sections concerned with specialised areas of activity: accounts, purchase, stores, establishment, public relations, filing, general administration, transport, security, cosmetic maintenance, canteen, parks and gardens; the technical maintenance services (which deal with electrical, air conditioning, civil engineering aspects), come under a technical Engineering Services Committee. In addition to these sections which are concerned with the general administrative aspects of the Institute as a whole, there are administrative offices attached to each of the Schools of Mathematics and Physics; and further secretarial staff is attached to each of the active groups. All of this is in the normal pattern of administration. What is particularly relevant is the clear emphasis and understanding that the administrative structure is to be regarded as a supporting aspect, to enable scientific research to be carried out with the greatest efficiency; administration is not an end in itself in the Institute, nor is it a dominant element. It is the administrative sections which have to interface with the outside world of banks,

suppliers, travel agents, customs, government departments and so on; and most of the delays that occur appear to be at this interface; in the purely internal administrative aspects of the Institute, efficiency is high, certainly compared to anything else that one normally encounters in the country: for example, great emphasis is laid on cleanliness of the buildings; the entire cleaning is carried out during the night to avoid inconvenience; the accounts of the Institute have always received very favourable comments from the auditors; whilst maintaining strictly all proprieties, appointments can in general be made in the Institute faster than in any governmental or government supported autonomous institute in the country. Dr. John Mathai, Professor R. Choksi and Shri E. C. Allardice gave Homi Bhabha all the necessary advice and support in the early days of the Institute to establish the foundations of this administrative structure.

Building Activities

An important phase in the construction of the permanent buildings of the Institute at Colaba was completed by the end of 1961; and it was to mark this stage in the history of the Institute that a formal function was arranged on January 15, 1962, when Prime Minister Jawaharlal Nehru inaugurated these buildings before a large and distinguished gathering. It is worth emphasising that the building activities of the Institute did not stop at that stage; and have been proceeding on a steady basis ever since then. In particular, under the auspices of the Institute, more building construction has been carried out,



Fig. 24 — The Homi Bhabha Auditorium.

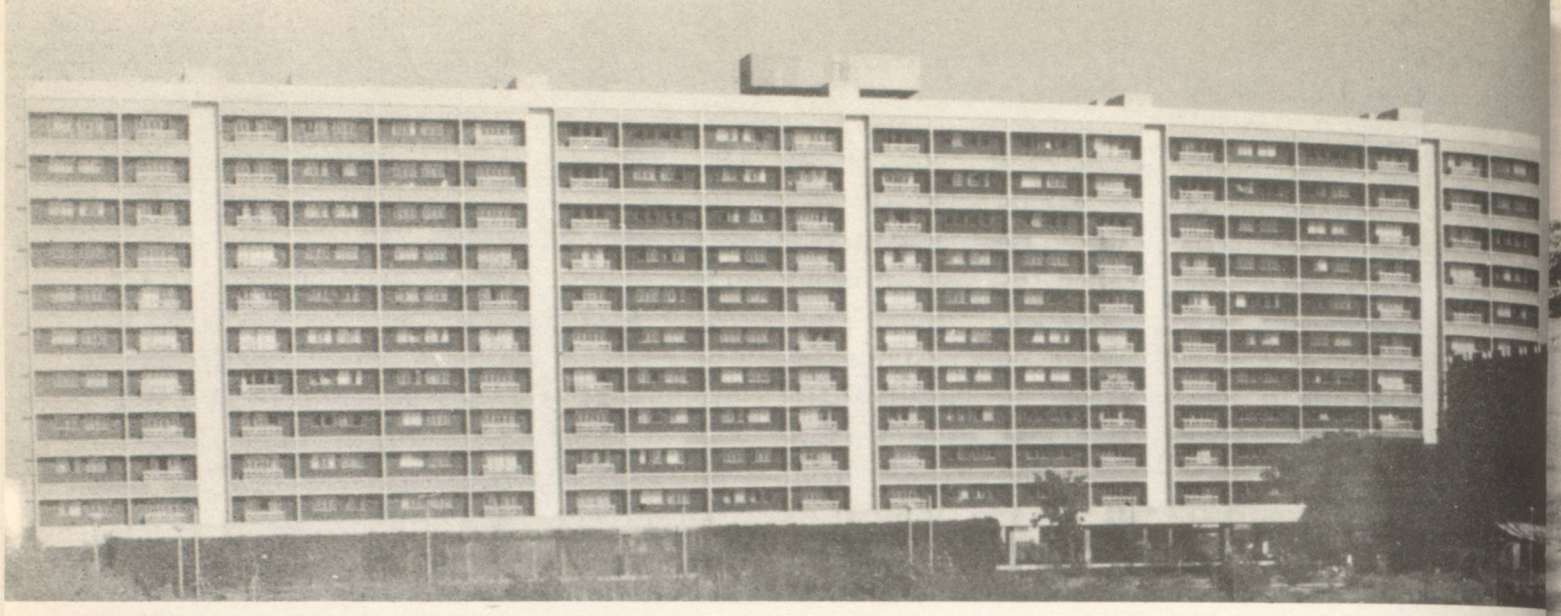


Fig. 25 — The ten storeyed building with 99 flats housing the Institute staff members.

in terms of money spent, since 1961 than during the entire period before. The construction carried out includes: (i) the 1,036-seating Homi Bhabha Auditorium and Museum Complex; (ii) two floors on 'B' Block, one to accommodate the Molecular Biology Group, and the other for the Cosmic Ray Group for its high altitude programmes based on the use of nuclear emulsions and electronic detector systems; (iii) the preparation of the launch ground and the construction of the balloon production facility and laboratory-cum-hostel complex of the National Balloon Facility at Maula Ali in Hyderabad; (iv) landscaping of the $\sim 11^{\circ}$ north-south slope at the Fairlawns site for setting up of the Ooty Cylindrical Radio Telescope, and the construction of the laboratory and hostel buildings there, as well as all other site facilities such as approach roads, water, electricity, etc. Additionally, two buildings in the Colaba Housing Colony have been put up; a 10-storeyed 450 feet long B1 Block, with 99 flats, in which most of the senior staff members of the Institute live; and the E1 Block with 124 single rooms and 16 efficiency apartments, which will be ready for occupation during summer 1971. The Colaba Housing Colony is owned by the Department of Atomic Energy, but the Institute has been assigned responsiblity for all aspects relating to the layout of buildings, architectural and engineering design, award of contracts, and supervision of construction.

To handle these aspects, the Institute has a small cell consisting of an Institute Architect and a Building Project Officer with their staff. All the members of this cell have been very kindly placed on deputation with the Institute by the Architecture and Civil Engineering (A. and C.E.) Division of the Bhabha Atomic Research Centre; they work under the guidance of senior staff of the A. and C.E. Division at Trombay. This cell deals with all aspects of building construction work; conceptual design, architectural drawings, detailed structural engineering designs, services (electrical, airconditioning, public health, etc.), and implementation of construction. This group is currently engaged on

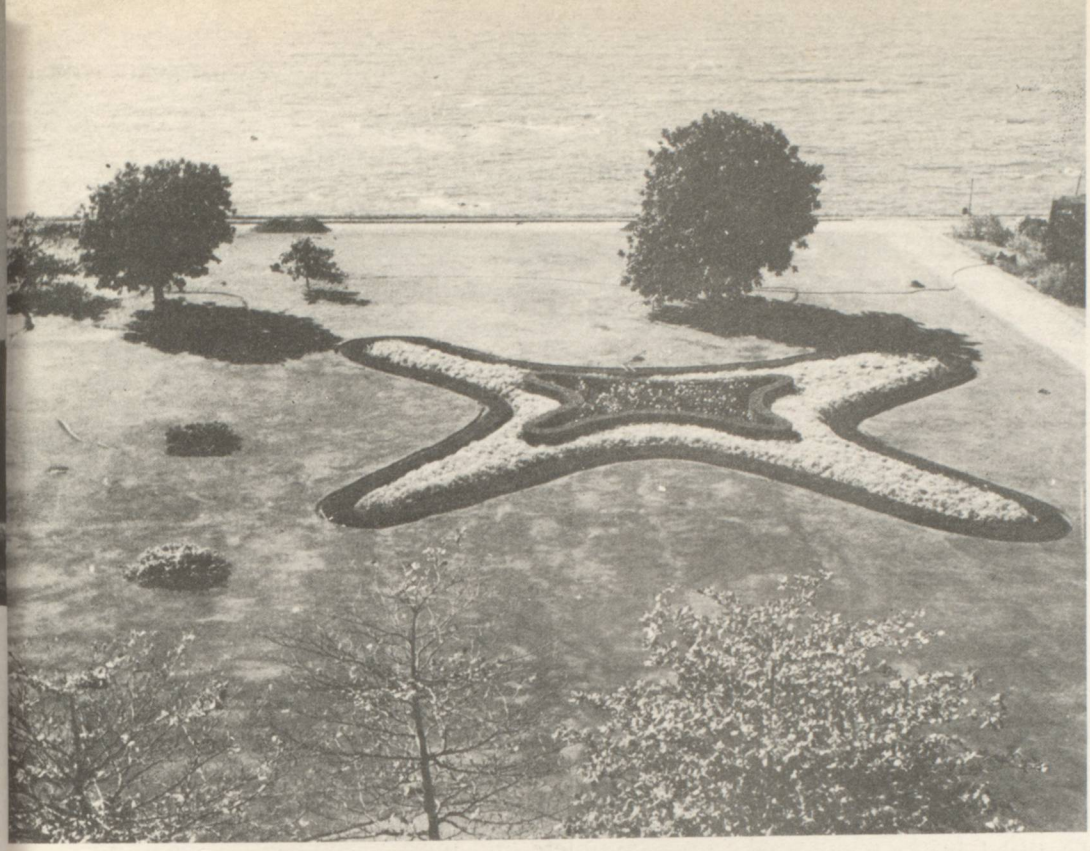


Fig. 26 – The west lawn.



Fig. 27 – Sculpture, "Mother and Child", in stone-cement, by Mohan Ghisad, in the terrace garden of the colonnade area.

a multi-storeyed building with a total floor space of 100,000 sq. ft. within the Institute compound which is primarily needed for a major computer centre. By having such a building project cell in the Institute carrying out feasibility and design studies it has been shown that there have been significant economies compared to a situation where outside consultants have to be engaged; this is of course related to the existence of tasks on a continuing basis on which such a group can work.

The Environment

The Institute, in many respects, reflects the personality that was Homi Bhabha. He was deeply interested in science and his greatest intellectual achievements were scientific; and the prime objective and characteristic of the Institute is scientific research. But Homi Bhabha was also interested in the many other facets which make up a complete life: music; architecture; painting and sculpture; landscapes, gardens, trees and flowers; good food, international friendship, and the application of science for the benefit of society. His interest in each one of these was deep; he was also a practical person; and he gave practical shape to these interests. All of this can be seen reflected in the Institute.

Gardens

The gardens of the Institute were carefully planned out. What was originally a site for coastal batteries was converted into a large expanse of



Fig. 28— View of the casuarina forest and transplanted trees on the southern side of the west lawn; the metal sculpture "man of war" is seen in the foreground.

green lawn and a small casuarina forest, both right on the sea front; with trees carefully located—some in their original places and others transplanted; with herbaceous borders; and a large car park for the Auditorium and Museum Complex in which the ugliness of metal and chromium, which is the main characteristic of a large assembly of modern cars, is hidden by high hedges.

Art collection

Over the past two decades, the Institute has regularly bought paintings. Many of these have been bought from artists exhibiting for the first time and at a relatively small price; but with discriminating taste and good artistic judgement, it has been possible to identify even at that stage artists who had



Fig. 29—Homi Bhabha showing the sculpture "Head of Einstein" by Sir Jacob Epstein to Shri M. C. Chagla, Education Minister, Government of India. Professor M. G. K. Menon, present Director of the Institute, is also seen in the picture.

potential for real creativity. And thus the Institute collection, (at present consisting of about 230 works of art), has grown to be one of the major collections of contemporary Indian art existing today. Indian art seen at the Institute is contemporaneous with its science; both cover the past quarter of a century of Indian creativity. There are a few exceptions; the head of Albert Einstein bought by Homi Bhabha from Sir Jacob Epstein; the Rajasthan temple pillar (9th century A.D.); several stone pieces of Chola period from South India (10th century A.D.) notably a large "Vishnu"; and wood carvings from Gujarat and South India. These works of art adorn the corridors, office rooms, museum area and the grounds of the Institute. And one does not feel the existence of any so-called "dichotomy of the two cultures."

With the commissioning of the Homi Bhabha Auditorium, music, dance, films and drama, have also become part of the environment of the Institute.

International links

From its early days the Institute has had a programme of inviting scientists from within the country and from abroad, to participate in the work of the Institute. Some of the very distinguished names in the world of mathematics and of physics figure in the list of visitors to the Institute. Many of them have stayed at the Institute to give courses of lectures, others to participate in summer schools which are organised on a regular basis, and yet others to work on collaborative experimental programmes. With regard to the latter, the Institute has had close relationships with several Institutions abroad. Some of these links are perhaps worth recording here: between the Geophysics Group and the Scripps Institute of Oceanography, La Jolla; between the Nuclear Physics Group and the Institute of Theoretical Physics, Copenhagen; between the Cosmic Ray Group and the University of Bristol, England, the University of Durham, England, the Danish Space Research Institute, Copenhagen, the Osaka City University, Japan, Nagoya University, Japan, and the Smithsonian Astrophysical Observatory, USA; between the Basic Dental Research Unit and the National Institutes of Health, USA, and the Royal Dental Hospital, Copenhagen; and many others. The Institute has received great co-operation from a variety of high energy accelerator laboratories in the world, notably from CERN in Geneva, and from the Argonne National Laboratory, USA, in connection with nuclear emulsion and bubble chamber experiments. Two major international programmes of balloon flights were carried out from Hyderabad, one in 1961 and the other in 1965. The School of Mathematics has close links with many schools abroad, particularly in France, Germany, England and USA. The Institute has the privilege of having amongst its Honorary Fellows outstanding scientists from all over the world. The Institute has arranged many international conferences in different areas of interest to it; the earliest of these was the 1950 Conference on Elementary Particles, held at the Old Yacht Club building.

The primary aim of the Institute has been to carry out fundamental research; this activity is an international one. The work done here has to be judged on international standards. And the Institute has thus to be very much part of an international scientific community; the links between the Institute and institutions abroad, as well as between scientists here and those abroad are characteristic of this.

Philosophy of Growth

Programmes built round men

No organisational chart of the future development of the Institute was submitted either when it was founded or later. The philosophy has always been to support ability whenever it has been found in the fields of work directly covered by the Institute or in related areas. In his letter to the Sir Dorabji Tata Trust, dated March 12, 1944, Homi Bhabha had pointed out



Fig. 30 — Group photograph taken at the time of the Conference on "Elementary Particles" organised by TIFR in 1950.

that the philosophy underlying the Max Planck Institute in Germany was: "The Kaiser Wilhelm Society shall not first build an Institute for research and then seek out the suitable man, but shall first pick up an outstanding man and then build an Institute for him".

The growth of the Institute has been based entirely on individuals who entered the Institute as students and developed through the programmes here into scientists of standing, or selected scientists working abroad who wanted to return to India to carry out scientific work here; two new areas, molecular biology and radio astronomy were recently developed on the basis of scientists trained and working abroad, who wanted suitable opportunities to work in India and who were willing to join the Institute.

In order to understand the significance of this philosophy, one has to compare the alternative normally practiced in India. In this alternative, areas of work are designated and staff positions advertised, indicating the job specifications and qualifications for intending candidates. A selection committee then chooses from among those who apply. Unless the quality of those who apply is really poor, the normal tendency is to appoint the best among those available.

Posts thus get filled, with the best available at an instant of time, rather than the best available over a period of time; the Institute has believed in choosing the latter category by a conscious search for talent, in the case of scientists and engineers engaged in research and development. The more standard method of recruitment is adopted for all other categories of staff.

In selecting new areas of work at the Institute, in addition to the philosophy of growing these round men of high quality, close attention is also paid to the manner in which these areas would integrate with the rest of the ongoing research at the Institute. This is to ensure that with the minimum additional investment one obtains the maximum return. Further it leads to the development of an interactive atmosphere which is conducive both to the growth of that which exists as well as that which is to be grown.

Philosophy of self-reliance

The Institute was founded with the objective of providing opportunities for scientists to work in the frontier fields of modern science. It was realised right at the beginning that this would involve the development and use of highly sophisticated techniques. Equipment for this type of work would clearly not be available in the country and, therefore, would either have to be imported or be made at the Institute. Whilst imports would be fully justified in the case of individual pieces of equipment that could be used for a wide range of programmes, in a variety of ways, and for extended periods of time and, therefore, could be considered as basic or common facilities, this would not be the case for items required on a continuing basis in large quantities.

On this line of reasoning the Institute has bought the following pieces of equipment as large scale facilities; the CDC 3600-160A Computer System; the 1 MeV Cockcroft-Walton High Voltage set; the Siegbahn-Slatis Intermediate Image β -ray Spectrometer; the Liquid Nitrogen and Liquid Helium Plants; the Varian High Resolution NMR Spectrometer; large Multi-channel Analysers; the Phillips Electron Microscope, etc. Each of these has been used very heavily, considerably modified over its life-time, and maintained and serviced by technical staff of the Institute.

On the other hand, for much of the work here, the Institute has had to build the equipment it needed; and for this to create a large and highly competent base of technical personnel in the broad areas of electronics, high vacuum, radiation detectors, mechanical engineering, chemical techniques, etc.

This can be seen from the experience from its earliest days. For experimental programmes in the areas of nuclear physics and cosmic rays it was essential to have radiation detectors, particularly counters of various types. One of the earliest activities of the Institute was, therefore, work relating to the development and production of counters of various types. This straightaway meant the setting up of a glass blowing and vacuum facility. The use of these counters as radiation detectors involved electronic units of various

types, (scalers, power supplies, etc.); and these were then designed. None of this work started from scratch; the objective was to develop, and have available, these techniques as rapidly as possible; and full advantage was taken of contemporary knowledge in this field elsewhere in the world; some of it was obtained by sending Institute staff to the appropriate places for training. As soon as the atomic energy programmes started to grow, counter systems and associated electronics were required in fairly large quantities for surveys for atomic minerals, for health physics, and for nuclear physics experimentation in general. The Institute, therefore, set up a "Development and Production Unit" (DPU) for pilot plant production of various required units. When this became a fairly large activity, DPU was transferred to the Atomic Energy Establishment at Trombay that had just then been set up, to be a part of its Electronics Division. At Trombay, the Electronics Division grew rapidly; and within a decade, when it was clear that, in scale and scope, further growth would be well beyond what would be appropriate at a research and development organization, the production activity was transferred to Hyderabad, to be the base of a public sector electronics factory called the Electronics Corporation of India Limited.

In similar fashion, the growth of the Technical Physics Division at Trombay started with initial work at the Institute on mass spectrometers, vacuum systems and radiation detectors, such as scintillating plastics and crystals, etc. Today the Technical Physics Division is one of the very productive and competent groups of the Bhabha Atomic Research Centre.

In the more recent past one can cite many examples which relate to the philosophy of self-reliance, and the building up of equipment and facilities here on an indigenous basis. The National Balloon Facility is now a major capability for carrying out research close to the top of the earth's atmosphere; this was a programme entirely developed at the Institute. The large cylindrical radio telescope at Ootacamund was conceived, designed and entirely fabricated indigenously. Various types of spectrometers (for wide-line magnetic resonance, electron spin resonance, etc.) were constructed locally for programmes in solid state physics and chemical physics. Several major precision instruments have been constructed at the Institute for work in nuclear physics, such as a single-gap high resolution magnetic beta ray spectrometer, a six-gap spectrometer with 12% transmission, and lithium drifted germanium detectors for gamma spectrometry. A time sharing facility with the CDC 3600 computer, involving four remote terminals was designed and implemented, including the total software needed for this. These are a few examples from different areas of work at the Institute; this list is by no means comprehensive. Efforts in this direction permeate the activities of all the groups at the Institute.

Competence building in areas of national interest

As a result of the research carried out in the Institute, a great deal of competence has been built in many areas of national relevance. It would be appropriate to cite a few examples to illustrate this. Work in the field of radio astronomy and the building of the very large cylindrical radio telescope at

Ootacamund has created the base for further work relating to steerable antennas needed for communication systems and radars, as also relating to low noise receiver systems. Work in the field of geophysics, based on the use of radioisotopes as tracers, has enabled the setting up of national facilities to tackle problems relating to archaeology, hydrology, meteorology, and oceanography; hydrological work is being carried out using three isotopes, tritium, silicon-32 and carbon-14; work on Indian archaeological horizons is being carried out using radio-carbon, neutron activation and metallurgical analysis; work in meteorology on the Indian monsoon is being carried out using a natural radionuclide radon. Competence in the area of computer sciences and technology was acquired through the design and fabrication of the first electronic digital computer in India (TIFRAC); this competence was immediately made use of for the maintenance and utilisation of the CDC 3600 computer system; this was followed by the design and building of an on-line computer OLDAP and several other hardware configurations. As a result of all this, and the considerable wide-based competence that it has given rise to, the Computer Group of the Institute is associated with a major programme of computer manufacture by the Electronics Corporation of India, Hyderabad (of computers that can be used as real time, on-line or general purpose systems); the major responsibility for the development of appropriate software is with the Institute. Further, in the Computer Group, methods of systems analysis, based on the availability of a large computer system, have been used for a variety of problems relating to the space programmes, transportation systems, electrical power networks including nuclear stations, etc. Core groups in areas of microwave engineering, solid state electronics, nuclear electronics, etc. came into existence on account of research activities at the Institute, where all these techniques have a significant role to play. In view of the importance of these sophisticated technologies, these groups have been considerably enlarged. And it is these groups which are now working, on the basis of contracts awarded by Government agencies, on the development of active and passive microwave devices, test equipment, parts of radar systems and so on. These are again only examples and by no means a comprehensive listing.

Tribute by the Institute to Homi Bhabha

Homi Bhabha died on 24th January, 1966, in an airplane crash on Mont Blanc, while on his way from Bombay to Geneva en route to Vienna where he was to attend meetings of the International Atomic Energy Agency. His passing away, and the manner of it, was a blow of a major magnitude to the Institute.

The greatest tribute that the Institute can pay to its founder is no doubt by fulfilling the expectations that he had of it. But the Council felt that it



Fig. 31 — Shri J.R.D. Tata, Chairman of the Council of Management of the Institute naming the main approach road to the Institute in honour of Homi Bhabha.

would also be appropriate for the Institute to pay its tribute in several immediately tangible ways.

It was decided to name as the Homi Bhabha Road the main concrete approach road to the Institute. Homi Bhabha was personally responsible for the alignment of this road and for the avenue of trees, the gulmohurs, the barringtonias, the peltophorums, and so on, that line it.

It was also decided to name, after Homi Bhabha, the Auditorium and Museum Complex that was under construction. Homi Bhabha had conceived of this complex and its basic design; he had obtained the necessary financial and administrative sanctions for constructing it. At the time of his death, work on it was in full swing; the basement had been completed, as also a great deal of the structural work. The auditorium was formally inaugurated and named the Homi Bhabha Auditorium by Prime Minister Shrimati Indira Gandhi on November 9, 1968; the first lecture to be given in it was the Homi Bhabha Memorial Lecture by Professor C. F. Powell on "The Aims and Role of Science in our Time".



Fig. 32—The Foyer and entrance to the Homi Bhabha Auditorium

On the occasion of the Silver Jubilee Year 1970-71, Council also decided that the Institute should hereforth celebrate 30th October each year, the birthday of Homi Bhabha, as Founder's Day. On the occasion of the first Founder's Day on 30th October 1970, the Institute, in honouring Homi Bhabha, decided to highlight a facet of his life, which was so important to him—his love for trees, flowers and gardens; and in doing this, also to say "thank you" to the city of Bombay, in which the Institute had grown so happily. The Institute presented to the City of Bombay several hundred trees for planting on Marine Drive, (Netaji Subhas Chandra Bose Marg). These trees, called Barringtonia



Fig. 33—Prime Minister Shrimati Indira Gandhi with Professor P.M.S. Blackett and Professor C.F. Powell in the Homi Bhabha Auditorium at the inaugural function on November 9, 1968.

Speciosa grow well near the sea, and have the ability to withstand the salt air and high winds characteristic of the Indian monsoon; after Homi Bhabha's death, these trees were grown in the gardens of the Institute for four years, close to the sea, with this specific objective in mind, of presenting them to the City of Bombay in honour of his memory.

Concluding Remarks

The basic aim of the Institute has been to be a Centre of Excellence in the fields in which research activity is carried out at the Institute. The implementation of this aim is important in several different ways.

Firstly, it provides a place where potentially brilliant scientists of the country can find opportunities to participate in first rate research, to partake in the excitement of new discoveries at the frontiers of human knowledge, and to become deeply motivated in the process; whilst they are engaged in research they still remain emotionally and culturally part of the country and its aspirations; and such roots add greatly to stability, mental satisfaction and motivation.

If there were no such places in the country, these scientists would look abroad for their opportunities; and having spent many years abroad, perhaps during the most impressionable periods of their lives, and with no satisfactory place to come back to, in order to continue such activity, these potential leaders would be permanently lost to the country.

Not only is the research of such men important; equally so is the role that they might play in the broader context of national development. Whilst it is true that some leaders in science confine themselves to their personal scientific interests, many more, particularly if they are deeply moved by the environment in which they live and work, find ways of exercising their intellectual abilities and their training in the scientific method, to provide badly needed leadership on a much wider front. Such centres of excellence would constitute islands of self confidence which can be so important in a country struggling to move forward rapidly.

A further important aspect of having such centres of excellence is that those who are trained abroad, especially the ones whom the country would particularly like to have back, can be expected to return only if they are provided opportunities here with work satisfaction.

Homi Bhabha believed, and this Institute shares that belief, that if it could be demonstrated that a country such as India could build institutions which would hold their own place in the world in the most advanced and sophisticated areas of human endeavour, institutions in which one could have a genuine pride for their quality of achievements and standards, a feeling would be generated that would be of tremendous practical and psychological importance to the country as a whole.

In its quarter of a century of existence, the Tata Institute of Fundamental Research has grown to be a large institution which is known internationally. During this period, it has played an important role in the early stages of the atomic energy programmes in India; and further, has developed viable and self-generating groups in many broad domains of scientific research; these groups provide support for one another and foster interdisciplinary work in areas at the forefront of scientific progress. To achieve this in the conditions which exist in India, it has also been necessary to develop in the Institute considerable competence in areas of applied science and technology.

Over the future the principal task of the Institute will be that for which it was founded, namely, the carrying out of fundamental research, and providing opportunities for young persons of the highest intellectual calibre in the country to train and work in areas at the forefront of human knowledge. At the same time, on account of its size, and the diversity of its interests and available technical know-how, it has started to play a meaningful role both in the field of education and in the field of applied research which has industrial applications. In this manner it is hoped that the continued development of fundamental research at this Institute will have a strong interaction with, and find deep roots in, practical and national problems.

COUNCIL OF MANAGEMENT

Present Council

1. Shri J. R. D. Tata, — *Chairman*
   Bombay House, Bruce Street, Bombay 1.
2. Prof. R. D. Choksi, M.A., — *Member*
   Bombay House, Bruce Street, Bombay 1.
3. Dr. V. A. Sarabhai, M.A., Ph.D., — *Member*
   Secretary to the Government of India, Department of Atomic Energy, Chhatrapati Shivaji Maharaj Marg, Bombay 1.
4. Dr. I. G. Patel, B.A.,Ph.D., — *Member*
   Secretary to the Government of India, Department of Economic Affairs, Ministry of Finance, New Delhi.
5. Dr. S. Dhawan, M.Sc.,Ph.D., — *Member*
   Director, Indian Institute of Science, Banglore 12.
6. Shri S. E. Sukthankar, I.A.S., — *Member*
   Secretary to the Government of Maharashtra, Department of Agriculture, Sachivalaya, Bombay 32.
7. Prof. M. G. K. Menon, Ph.D.,F.R.S., — *ex officio Member*
   Director, Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay 5.

Members who have served on the Council in the past

1. Shri Sohrab N. Moos, M.A. (Cantab), C.I.E.,I.E.S.	1945-1950
2. *Dr. Homi J. Bhabha, D.Sc., F.R.S.	1945-1966
3. *Sir Sohrab D. Saklatvala, Kt. (Chairman)	1945-1948
4. *Dr. John Matthai, D.Sc. (London), C.I.E.	1945-1946
5. *Sir Ardeshir R. Dalal, K.C.I.E., I.C.S. (Chairman)	1946-1949
6. *Dr. Shanti Swarup Bhatnagar, D.Sc., F.R.S.	1947-1954
7. Shri D. C. Pavate, M.A. (Cantab)	1950-1955
8. Shri S. S. Bhandarkar, B.A. (London)	1955-1957
9. *Shri M. V. Rangachari, I.A. & A.S.	1955
10. Shri P. C. Bhattacharya, I.A. & A.S.	1955-1957
11. Shri S. Ratnam, I.A. & A.S.	1957-1959
12. *Shri V. T. Dehejia, I.C.S.	1957-1960
13. Shri N. N. Wanchoo, I.C.S.	1958-1961
14. Shri P. N. Thapar, I.C.S.	1958-1962
15. Shri M. R. Yardi, I.C.S.	1960-1962
16. Shri S. Jagannathan, I.C.S.	1962-1968
17. Shri P. N. Damry, I.A.S.	1962-1965
18. Shri V. M. Joshi, I.C.S.	1965
19. Shri M. V. Deo, I.A.S.	1965-1967
20. Shri Dharma Vira, I.C.S.	1966

HOLDING TRUSTEES

Holding Trustees (Present)

1. Shri Naval H. Tata, Bombay House, Bruce Street, Bombay 1.
2. Shri B. Venkatappiah, Member, Planning Commission, New Delhi.
3. Shri S. E. Sukthankar, Secretary to the Government of Maharashtra, Department of Agriculture, Sachivalaya, Bombay 32.

Holding Trustees (Past)

1. *Shri P. G. Shah, I.A.&A.S.
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3. Shri V. Iswaran, I.C.S.
4. *Shri V. T. Dehejia, I.C.S.
5. Shri M. V. Deo, I.A.S.
6. Shri M. R. Yardi, I.C.S.

*passed away.

HONORARY FELLOWS

The Rules and Bye-laws of the Institute provide for the conferment of Honorary Fellowships by the Institute. The Honorary Fellowship is the highest distinction that the Institute can confer on any individual.

Bye-law 7.1, which is concerned with this matter, reads as follows:

> "The Council may, on the recommendation of the Director, appoint Honorary Fellows. Honorary Fellowships may be conferred by the Council on eminent scholars in recognition of their distinguished contribution to knowledge in subjects in which the Institute is interested, or on persons who have rendered eminent service to the Institute, or on persons who have made a noteworthy and lasting contribution to the cause of fundamental research in India. Honorary Fellows shall enjoy such privileges as may be decided by the Council from time to time."

There is no doubt that there are many scientists in the world who have made outstanding contributions to knowledge in areas in which the Institute is interested; but in conferring Honorary Fellowships the Institute has been guided by the consideration that Honorary Fellows, in addition to being persons of eminence in their own right, should have had close connections with the Institute and with India. Most of the Honorary Fellows of the Institute have spent extended periods of time in residence at the Institute, have initiated research programmes at the Institute and have had staff members of the Institute work under them.

An Honorary Fellow has the privilege of being in residence at the Institute, at any time he likes, on his own initiative, for a specified period, which at present is one month in every year; and would receive a sum as may be fixed by the Council towards the expenses of such residence, without reference to any other payments that he may receive from the Institute or from elsewhere for his visit and work here.

During the first quarter of a century of its existence, the Institute conferred Honorary Fellowships on: Dr. John Mathai, Prof. P.A.M. Dirac, Shri Jawaharlal Nehru, Prof. C.L. Siegel, Prof. Niels Bohr, Sir John Cockcroft, Lord P.M. S. Blackett, Prof. C.F. Powell, Sir C.V. Raman and Shri J.R.D. Tata in that order.

During the Silver Jubilee Year of the Institute, 1970-71, the Council of Management felt that it would be appropriate to confer Honorary Fellowships on several scientists who have made outstanding contributions to science in areas of direct interest to the Institute, who have a deep and abiding interest in this Institute and in India, and whose support and encouragement has been essential for the growth of the Institute to its present standing in the international scientific community. Accordingly Honorary Fellowships have been conferred on: Prof. Hannes Alfven, Prof. Felix Bloch, Prof. S.N. Bose, Prof. S. Chandrasekhar, Prof. K. Chandrasekharan, Prof. Murray Gell-Mann, Prof. Harish Chandra, Prof. Hargobind Khorana, Prof. Bernard Peters, Prof. Bruno Rossi, and Prof. Laurent Schwartz. A brief write-up on each of these Honorary Fellows is contained in this section of the Report.

MATHAI, JOHN: (1886-1959)

Educationist and economist. He was a Member of the first provisional Council of Management of the Institute which met in May 1945. He continued to be a Member of the Council until his departure for Delhi in 1946 to become Finance Minister in the Government of India He was largely responsible for setting the pattern of administration of the Institute when it was founded and for the interest taken by the Government of India in the Institute in the beginning.

The First Honorary Fellowship of the Institute was conferred on him, in 1947, in recognition of the great services he had rendered to the Institute.

NEHRU, JAWAHARLAL (1889-1964)

Science was an essential, indeed basic, component of the India which Jawaharlal Nehru sought and worked so hard to build. And he always gave science his powerful and unfailing support.

He laid the foundation stone of the permanent buildings of the Institute in Colaba on 1st January 1954 and inaugurated these buildings on 15th January 1962. In addition, he visited the Institute on several other occasions. The development of the Institute to its present proportions and standing owes greatly to the steady support and encouragement that he gave it.

The Honorary Fellowship of the Institute was conferred on him in 1957 in recognition of his eminent service to the cause of science in India and his close personal links with the Institute.

DIRAC, PAUL ADRIEN MAURICE:(1902-)

Emeritus Lucasian Professor of Mathematics in the University of Cambridge, England; Nobel Laureate, Physics, 1933.

The Royal Society of London: Elected Fellow in 1930; Bakerian (1941) Lecture; Royal (1939) and Copley (1952) Medals.

He was in residence at the Institute as a Visiting Professor in 1954, when he gave an extensive course of lectures on Quantum Mechanics and Relativistic Field Theory.

The Honorary Fellowship of the Institute was conferred on him in 1958, for his epoch-making contributions to science in the broad areas of quantum mechanics, the quantum theory of radiation, quantum statistics and the relativistic theory of the electron, and for the support that he gave to the Institute in its early days.

SIEGEL, CARL LUDWIG:(1896-)

Emeritus Professor at the Mathematical Institute, Göttingen. He was Professor at the Institute for Advanced Study, Princeton, USA from 1940 to 1957. Member of the French Academy 1956; Order of Merit of the Federal Republic of Germany.

He has been in residence at the Institute as a Visiting Professor in 1955, 1962 and 1966. Several mathematicians of the Institute have worked with him and have been greatly influenced by his work.

The Honorary Fellowship of the Institute was conferred on him in 1959 for his epoch-making contributions over a wide range of Mathematics and for his close links with the Institute and its research activities.

BOHR, NIELS HENRIK DAVID:(1885-1962)

Professor of Theoretical Physics at the University of Copenhagen from 1961; Founder-Director of the Institute of Theoretical Physics, Copenhagen, from 1926; Nobel Laureate, Physics, 1922; first Atoms for Peace Award, 1957.

The Honorary Fellowship of the Institute was conferred on him in 1960 on the occasion of his residence in the Institute, in recognition of his epoch-making contributions to science which laid the foundations of our present-day knowledge

of atomic and nuclear physics and quantum mechanics, for his outstanding leadership in science for half a century and for the warm friendship he always extended to the Institute.

COCKCROFT, JOHN DOUGLAS:(1897-1967)

O.M., K.C.B., C.B.E.,

Jacksonian Professor of Physics in the Cambridge University, England (1939-1946); held a variety of posts connected with the atomic energy programmes in UK during and after the Second World War; in particular he was Director of the Atomic Energy Establishment, Harwell, England (1946-1958); Master of Churchill College, Cambridge University (1960-1967); Nobel Laureate, Physics, 1951; Atoms for Peace Award, 1961.

The Royal Society of London: Elected Fellow in 1936; Hughes (1938), Royal (1954) Medals; Rutherford Memorial Lecture 1952.

The Honorary Fellowship of the Institute was conferred on him in 1964, for his outstanding contributions to Physics in areas of direct interest to the Institute, his distinguished work in the field of atomic energy and the valuable support he gave to the Indian atomic energy programme in its early days.

BLACKETT, OF CHELSEA IN GREATER LONDON, PATRICK MAYNARD STUART:(1897-)

Baron, O.M., C.H., U.S. Medal of Merit; Nobel Laureate, Physics, 1948; Emeritus Professor of Physics in the University of London.

The Royal Society of London: Elected Fellow in 1933; Bakerian (1934) and Rutherford Memorial (1958) Lectures; Royal (1940) and Copley (1956) Medals; President (1965-1970).

First foreign physicist to lecture at the Institute (1947); initiated research in palaeomagnetism at the Institute (1955); Nehru Memorial Lecture, New Delhi (1967); has visited the Institute on many occasions.

The Honorary Fellowship of the Institute was conferred on him in 1968 for his outstanding contributions to science, in particular in the areas of cosmic ray physics, operations research and palaeomagnetism, and his deep and abiding interest in the welfare of India and of this Institute.

POWELL, CECIL FRANK:(1903-1969)

Melville Wills Professor of Physics (1948-1963) and then Henry Overton Wills Professor of Physics (1964-1969), in the University of Bristol, England; Nobel Laureate, Physics, 1950.

The Royal Society of London: Elected Fellow in 1949; Hughes (1949) and Royal (1961) Medals; Bakerian (1957) and Tercentenary (1961) Lectures; USSR Academy of Sciences: Foreign Member and Lomonosov Gold Medal (1968).

One of the eleven signatories of the Bertrand Russell-Albert Einstein Manifesto (1955) which started the Pugwash Movement; Chairman of the Continuing Committee of the Pugwash Conferences, until his death in 1969.

Delivered the First Homi Bhabha Memorial Lecture at the Institute (1968); has visited India on several occasions, (1956, 1963, 1964, 1968); several senior scientists of the Institute worked closely with him; there has been extensive collaboration between his group in Bristol and the Institute.

The Honorary Fellowship of the Institute was conferred on him in 1968, for his outstanding contributions to science, in particular the development of the photographic emulsion technique and discoveries in meson physics, his close personal links with India and with the Institute, and the enduring role that he played in the Pugwash Movement.

RAMAN, CHANDRASEKHARA VENKATA:(1888-1970)

Palit Professor of Physics at Calcutta University (1917-1933); Director of the Indian Institute of Science, Bangalore (1933-1937); Professor of Physics at the Indian Institute of Science, Bangalore, (1937-1948); Founder-Director of the Raman Research Institute, Bangalore (1948-1970); National Professor (1949-1970).

Nobel Laureate, Physics, 1930; Knighted (1929); Bharat Ratna (1954); Matteucci Medal of the Italian Academy of Sciences (1928); Franklin Medal (1941); Lenin Peace Prize (1958).

The Royal Society of London:Elected Fellow in 1924; Hughes Medal (1930); Foreign Associate of the French Academy of Sciences.

The Honorary Fellowship of the Institute was conferred on him in 1968, for his outstanding work in science, in wide areas of optics and acoustics, notably the scattering of light and the discovery of the effect named after him, and for his noteworthy and lasting contributions to the cause of fundamental research in India.

TATA, JEHANGIR RUTTONJI DADABHOY:(1904-)

The Institute came into being on account of the encouragement and support that he gave to Homi Bhabha in 1943. He was nominated Member of the Council of Management of the Institute by Sir Dorabji Tata Trust in 1948; he became Chairman of the Council in 1950 and continues to hold this position. As Member and Chairman of the Council he has rendered eminent service to the Institute, through his appreciation and understanding of the needs of science. His wide experience of public life and mature judgement have been decisive in ensuring that the Institute developed on the right lines.

He has made noteworthy and lasting contributions to the cause of fundamental research in India by his work in the service of this Institute, of the Indian Institute of Science, Bangalore, of the various Trusts which provide support for scientists and scientific institutions and in the setting up of the Homi Bhabha Fellowships Council. Through his long and devoted service he has brought prestige to the field of Indian Aviation.

The Honorary Fellowship of the Institute was conferred on him in 1968 in recognition of the above.

CHANDRASEKHARAN, KOMARAVOLU:(1920-)

Was at the Tata Institute of Fundamental Research from 1949 to 1965; Senior Professor and Deputy Director (Mathematics) at the Institute 1960-1965; since 1965, Professor at Eidgenossische Technische Hochschule, Zurich.

The Honorary Fellowship of the Institute was conferred on him, during the Silver Jubilee Year 1970-1971, in recognition of his distinguished contributions to Mathematics, particularly in the areas of Analysis and Number Theory, and for the unique and decisive role that he played in creating and fostering the School of Mathematics of the Institute.

HARISH CHANDRA:(1923-)

Professor at the Institute for Advanced Studies, Princeton, USA, since 1963; Frank Nelson Cole Prize 1954. He has made outstanding contributions to Mathematics, particularly to the theory of Representations of Lie Groups and Lie Algebras. He was in residence at the Institute as a Visiting Professor in 1952.

The Honorary Fellowship of the Institute was conferred on him, during the Silver Jubilee Year 1970-1971, in recognition of his distinguished contribution to Mathematics and his association with the Institute during the early days.

SCHWARTZ, LAURENT:(1915-)

Professor at the Ecole Polytechnique, Centre de Mathematiques, Paris and Member of the French Academy. He was awarded the Fields Medal at the International Congress of Mathematicians, Cambridge, USA, in 1950. He has been in residence at the Institute as a Visiting Professor in 1955, 1957 and 1965.

The Honorary Fellowship of the Institute was conferred on him during the Silver Jubilee Year 1970-1971, for his outstanding work in Mathematics in the area of Analysis and in particular on the Theory of Distributions, and for his abiding interest in, and valuable support to the development of the School of Mathematics of the Institute.

ALFVEN, HANNES:(1908-)

Was in succession Professor of Theoretical Electrodynamics (1940-1945); of Electronics (1945-1964) and of Plasma Physics (1964-) at the Royal Institute of Technology, Stockholm; currently also at the University of California at San Diego, USA; Nobel Laureate, Physics, 1970; President of the Pugwash Movement since 1970.

He was in residence in the Institute for an extended stay in 1958 as a Visiting Professor.

The Honorary Fellowship of the Institute was conferred on him during the Silver Jubilee Year 1970-1971, for his pioneering work in magnetohydrodynamics with its wide-ranging applications in geophysics, planetary sciences, astrophysics and plasma physics, and for the close links he has maintained with the Institute and its staff members, and for his deep interest in India.

BLOCH, FELIX:(1905-)

Professor of Physics at Stanford University since 1936. Was Director General of CERN, Geneva, 1954-1955. Nobel Laureate, Physics, 1952. Was a Visiting Professor at the Institute in 1962. Several senior scientists of the Institute worked closely with him; and this formed the basis for the initiation of work in magnetic resonance at the Institute.

The Honorary Fellowship of the Institute was conferred on him during the Silver Jubilee Year 1970-1971 for his outstanding work on a wide range of topics covering notably the discovery of nuclear induction, and for his close links with the Institute and its research activities.

BOSE, SATYENDRA NATH:(1894-)

National Professor; and Emeritus Professor of Physics in the University of Calcutta. Elected Fellow of the Royal Society of London in 1958. He discovered a fundamental law governing statistical behaviour of photons which laid the foundation of quantum statistics and provided the key for solving the problem of gas degeneracy; the extension of this law to massive particles by Einstein gave birth to the well known Bose-Einstein statistics.

The Honorary Fellowship of the Institute was conferred on him during the Silver Jubilee Year 1970-1971, for his outstanding and enduring contribution to science and for furthering the cause of science in India.

CHANDRASEKHAR, SUBRAHMANYAN:(1910-)

Morton D. Hull Distinguished Service Professor in the University of Chicago since 1952; Bruce Gold Medal in Astronomy (1953); Gold Medal of the Royal Astronomy Society (1953), Rumford Medal of the American Academy of Sciences (1957) and the National Medal of Science, USA (1966).

The Royal Society of London: elected Fellow 1944; Royal Medal (1962).

The Honorary Fellowship of the Institute was conferred on him, during the Silver Jubilee Year 1970-1971, for his outstanding and enduring contribution to Astrophysics and for his interest in the Institute from its earliest days.

GELL MANN, MURRAY:(1929-)

Professor of Physics at the California Institute of Technology, Pasadena, California, USA, since 1956. Nobel Laureate, Physics, 1969; Heineman Prize of the American Institute of Physics (1959).

He lectured at the first Summer School in Theoretical Physics organised by the Institute in Bangalore in 1961; this was a turning point in the development of theoretical physics at the Institute and also to some extent in India.

The Honorary Fellowship of the Institute was conferred on him during the Silver Jubilee Year 1970-1971, for his distinguished contributions to high energy elementary particle physics, in areas in which the Institute is directly interested, and for his close association with the Institute which have been important for its development.

KHORANA, HAR GOBIND:(1922-)

Professor at the Massachusetts Institute of Technology, Cambridge, USA Nobel Laureate, Physiology and Medicine, 1969.

The Honorary Fellowship of the Institute was conferred on him during the Silver Jubilee Year 1970-1971, for his outstanding contributions to biology, notably the deciphering of the genetic code and the total synthesis of a gene.

PETERS, BERNARD:(1910-)

Professor of Physics at the Tata Institute of Fundamental Research from 1952 to 1959; in 1959 he became Professor at the Institute of Theoretical Physics, Copenhagen; since 1966, Director of the Danish Space Research Institute, Lyngby.

The Honorary Fellowship of the Institute was conferred on him, during the Silver Jubilee Year 1970-1971, for his distinguished work in cosmic ray physics, high energy physics and geophysics, a great deal of which was done whilst he was a staff member of the Institute, and for the eminent service that he has rendered to the Institute and thereby to the cause of fundamental research in India.

ROSSI, BRUNO BENEDETTO:(1905-)

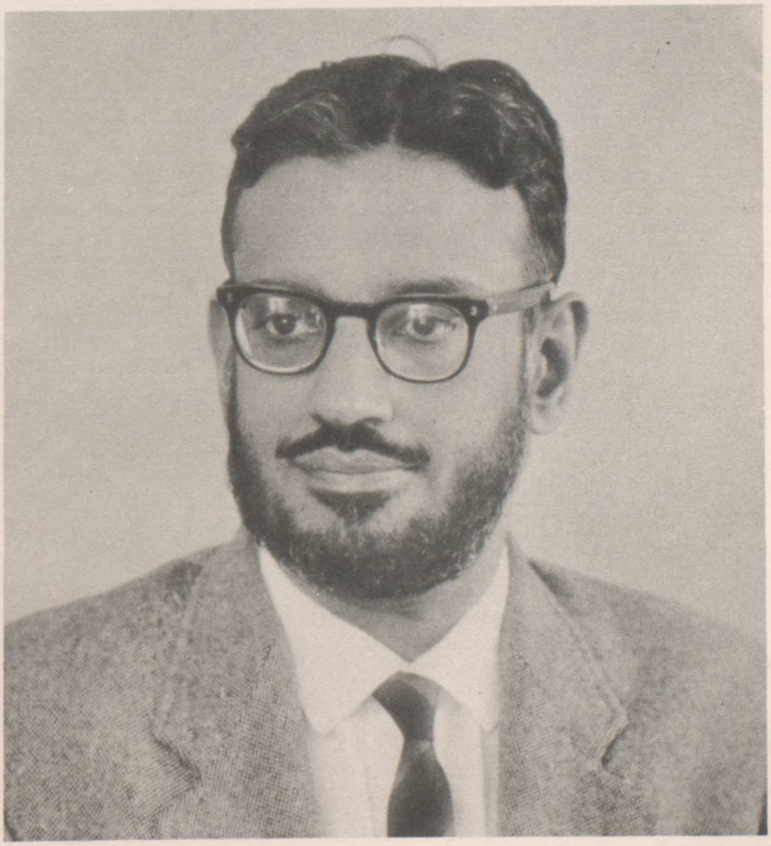
Professor at the Massachusetts Institute of Technology, Cambridge, Mass, USA since 1946. He was a Visiting Professor at the Institute in 1968. Several senior scientists of the Institute have worked closely with him. He was one of the outstanding personalities associated with the history and development of cosmic ray physics, an area of direct interest to the Institute.

The Honorary Fellowship of the Institute was conferred on him during the Silver Jubilee Year 1970-1971, for his great contributions to cosmic ray physics and X-ray astronomy and his close personal links with the Institute.



HOMI J. BHABHA, F.R.S.
(1909-1966)

Founder Director, 1945-1966



M.G.K. MENON, F.R.S.
(1928-)

Deputy Director (Physics),
1964-1966

Director, 1966-



K. CHANDRASEKHARAN
(1920-)

Deputy Director (Mathematics)
1960 - 1965
Honorary Fellow of the Institute



E.C. ALLARDICE, I.C.S.
(1914 - 1969)

Deputy Director (Administration),
1953 - 1963



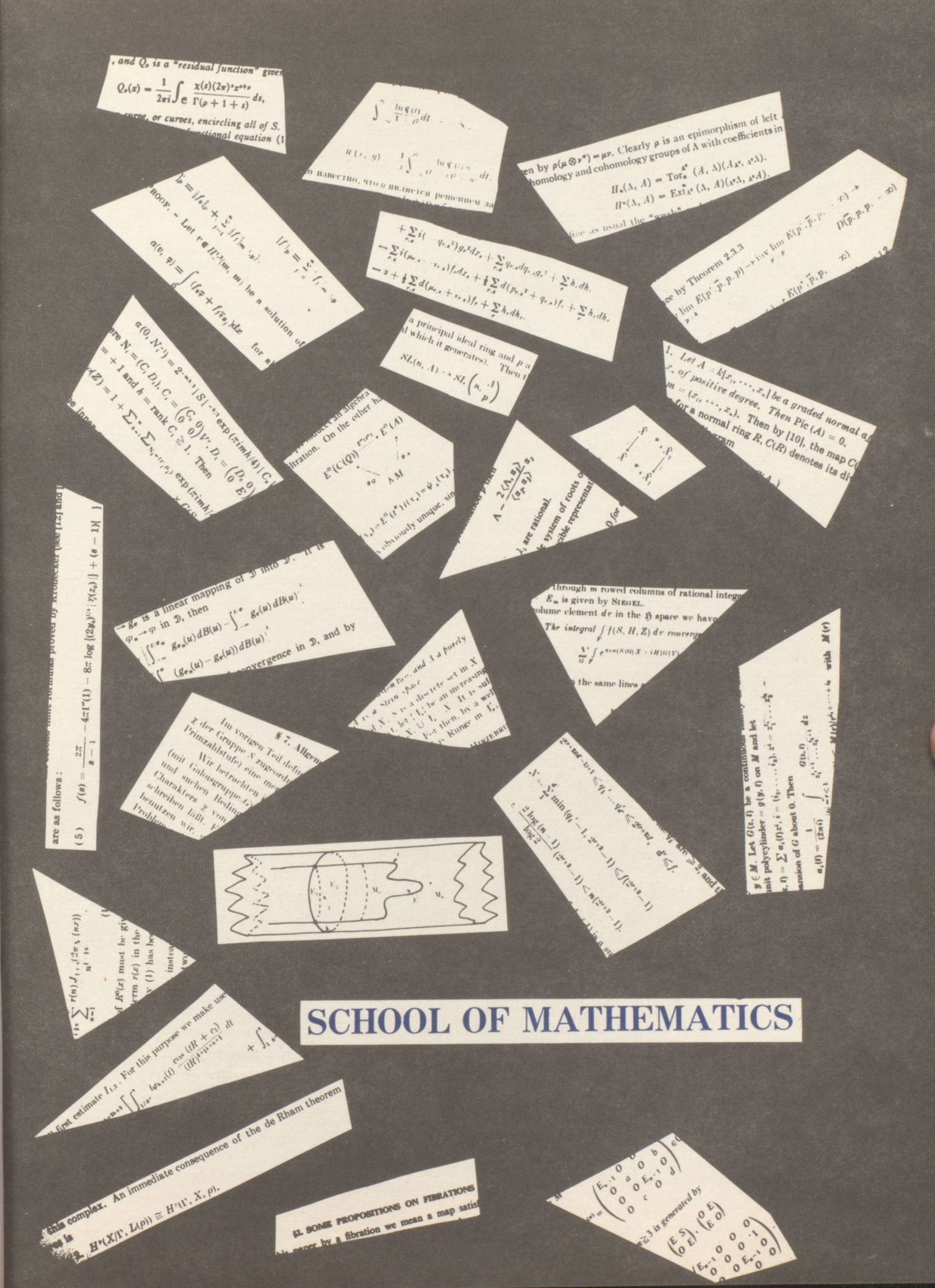
SIR SORAB D. SAKLATVALA
(1879 - 1948)

Chairman of the Council
of Management,
1945 - 1948



SIR ARDESHIR R. DALAL
(1884 - 1949)

Chairman of the Council
of Management
1948 - 1949



SCHOOL OF MATHEMATICS

SCHOOL OF MATHEMATICS

Background

Around 1945, when the Institute was founded, mathematical research of quality in India was confined to a very small number of university departments and was on a scale quite meagre by comparison with the basic human talent available in the country; it was centred round a few devoted individuals who had to function in a set up which was far from favourable. There was clearly a need to tap this latent talent and give it a sense of direction. Dr. Bhabha realised that Mathematics had an important role to play in any programme of fundamental research; and accordingly, the Institute from its earliest days had some mathematicians on its Faculty. It was, however, only after Professor K. Chandrasekharan joined the Institute in 1949, that serious consideration was given to a plan for organising a full-fledged School of Mathematics, for promoting mathematical research at the highest level in fields of current interest.

Professor Chandrasekharan initiated a programme for building up a School in the best international traditions of mathematical research. The first task was to produce within the next few years a body of good mathematicians and attention was directed to this. In accomplishing this task, Professor K.G. Ramanathan, who had joined the Institute by this time, gave his energetic support.

Development of the School

The research tradition in India was by and large confined to classical analysis, number theory, local differential geometry and applied mathematics. It was clearly necessary to introduce Indian research workers to other fields of live interest in mathematics, while improving still further the quality of work in the traditional fields. This involved two aspects, relating to the teachers and the students. As for the latter, there was no dearth of mathematical talent; what was needed was to locate it by a stringent method of selection and then to nourish it painstakingly. As for the former, there were practically no experts in India at the time in some fields in the forefront of world research, and it was necessary to fall back on the willing co-operation of the international mathematical community. It was therefore decided to invite from time to time acknowledged experts in carefully selected fields and to introduce the younger members of the School to their work. This supplemented the intensive preparatory training they had already at the Institute. It was seldom found necessary to force interests or to give specific assignments to students. The activities of the School centred around formal lectures and seminars, both by the Faculty and the visitors; and the equally important informal contacts between teacher and student, and student and student. It might be emphasised that while research is the primary objective, advanced training in mathematics in the form of lecture courses and seminars has been, and continues to be, an important activity.

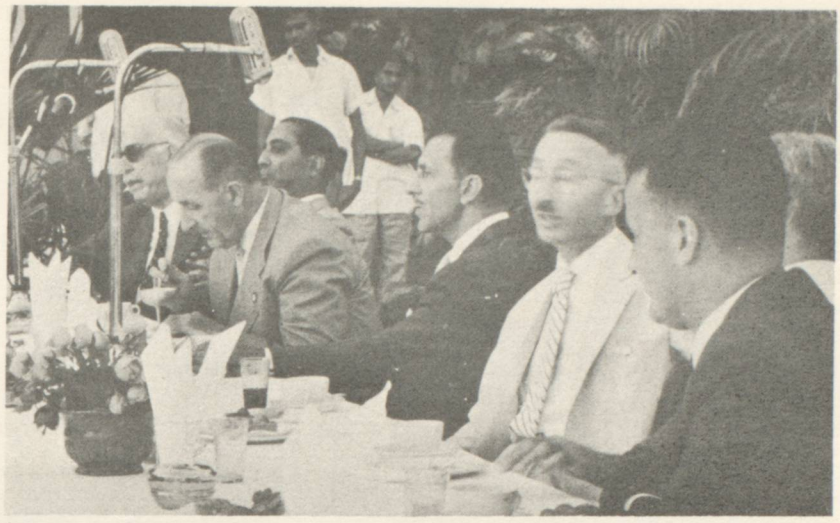


Fig. 1 — Prof. Neils Bohr, Dr. H.J. Bhabha, Prof. C.L. Siegel, Mr. J.R.D. Tata and Prof. H. Cartan at a reception held in connection with the International Colloquium on Function Theory held at the Institute in 1960.

Areas of research

Within three to four years, this carefully planned programme started yielding rich dividends. Over the past two decades the size of the School of Mathematics had expanded to about 60 and the interests of the School cover several major fields of present day interest. There are definitive groups of scholars working in Algebra, Number Theory, Lie Groups, Differential Geometry, Algebraic Geometry, Topology and Analysis. The appended list of publications gives some idea of the fields of interest and definitive achievements in each. By now the School has come to be recognised internationally as a leading centre of research in mathematics. Several members of the School have been invited as Visiting Professors by leading universities in the world and to give addresses in International Colloquia and in the various International Congresses of Mathematicians.

The work of the School has been stimulated by periodical visits of leading scholars from abroad and by visits of the members to major centres of mathematical activity abroad. International collaboration has been furthered by the holding of

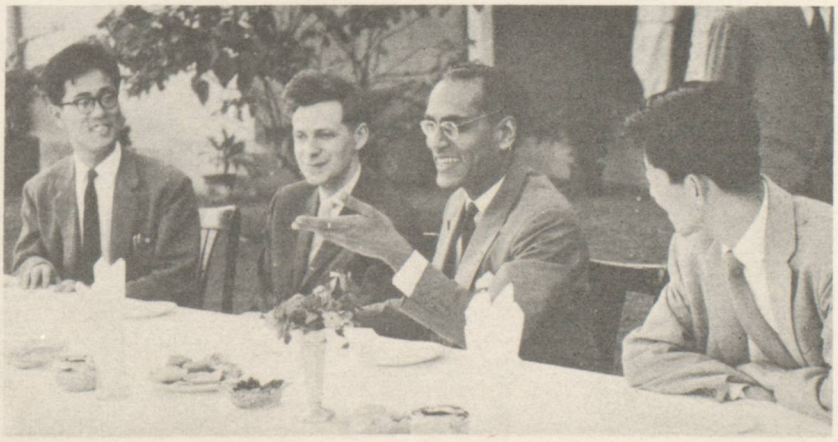


Fig. 2 — Professors R. Kawai, H. Grauert, K. Chandrasekharan and M. Kuranishi — International Colloquium on Function Theory held at the Institute in 1960.



Fig. 3 — Professors D.C. Spencer and G. de Rham at the International Colloquium on Differential Analysis held in Bombay in 1964.

research colloquia by the School; so far four of these have been organized, on Zeta Functions in 1956, on Function Theory in 1960, on Differential Analysis in 1964 and on Algebraic Geometry in 1968.

Mathematical research and education

In Mathematics, as in other subjects, research and education mutually interact. Only a good system of mathematical instruction in the universities can ensure a continuous flow of talent into the research institutions. The School was seized of



Fig. 4 — Professors A. Grothendieck, K.G. Ramanathan, Y.I. Manin, M.S. Narasimhan, J.W.S. Cassels (all in the rear), A. Borel, C.S. Seshadri and P.A. Griffiths (in the foreground) — International Colloquium on Algebraic Geometry held in Bombay in 1968.

this problem early and as a modest beginning got itself interested in problems relating to the teaching of mathematics in the University of Bombay; in these efforts, it has received the full co-operation of the University. This has resulted in up-to-date revisions of the courses of study; and members of the Institute are represented on the University's Board of Studies in Mathematics and have conducted several post-graduate courses. This collaboration with the Bombay University has subsequently assumed a more formal shape in relation to the Centre for Advanced Study in Mathematics set up at the Bombay University under the auspices of the University Grants Commission. Contacts have been established with other Indian universities and there is a regular programme of exchange. For some years past the School has been conducting summer schools for university teachers and research scholars annually; so far there have been seven, in Algebraic Topology, Riemann Surfaces, Galois Theory, Analytic Number Theory, Functional Analysis, Semi-simple rings and Lie groups. There are arrangements by which members of university departments can work at the Institute as Visiting Members and this facility is being progressively made use of. The School also conducted international colloquia on mathematical education in South East Asia in 1956 and 1960.

Publications

Publications form another major activity of the School. Lecture Notes of practically every advanced course given in the Institute have been mimeographed and made available to the mathematical public at a nominal price; to date they number 46. The Proceedings of all Colloquia organised by the School are also available in print. The lectures delivered at the successive summer schools have subsequently been brought out as Mathematical Pamphlets, making a useful addition to the scanty literature published in India, thus partially fulfilling the need for good text books. The School also brings out books in a series of Monographs relating to specialized fields of research, and a series of Studies devoted to a

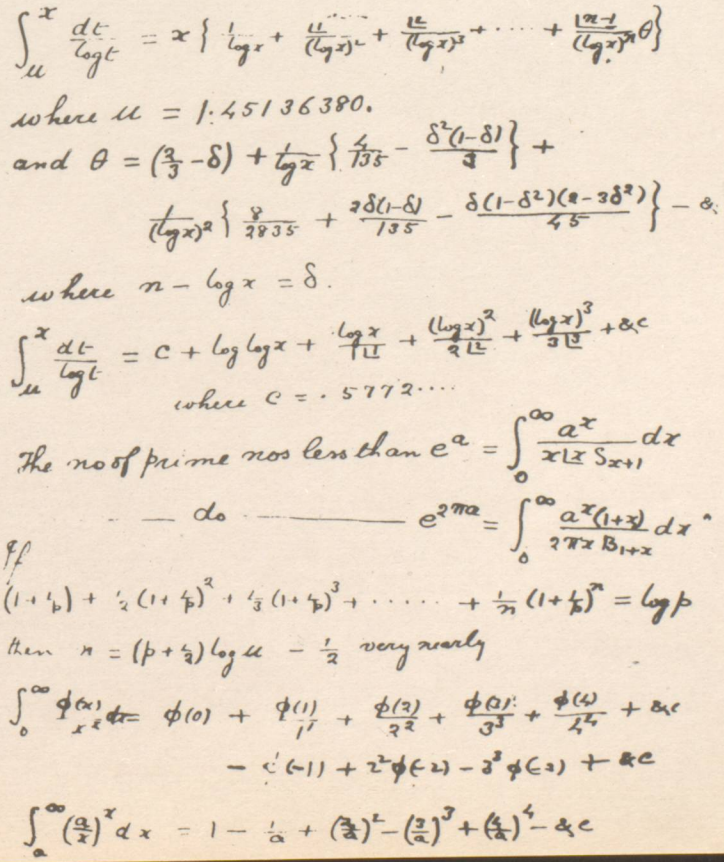


Fig. 5—A page from Srinivasa Ramanujan's Note Book.

high level treatment of subjects of current interest. The School was also instrumental in bringing out a photostat reproduction of the famous unpublished notebooks of Srinivasa Ramanujan.

Relations with other bodies concerned with mathematics

The School has been maintaining contacts with the Indian Mathematical Society (IMS) and its members have served on the Council of the Society and on the editorial boards of the Society's periodicals. Indeed the latter were brought out by the School from 1949—1959 and after a gap of years, again since 1969. Members of the School have participated in the academic programme of the IMS Conferences.

The School has also kept up organizational contacts with the International Mathematical Union. It was responsible for bringing out the Union's World Directory of Mathematicians in three successive editions. Several members of the School have served on the Indian National Committee for Mathematics.

SCHOOL OF MATHEMATICS

Papers Published in Scientific Journals

1949

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Am. J. Math., *LXXI*, 1, 50-59, 1949.

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Duke Math. J., U.S.A. *16*, 4, 579-583, 1949.

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Proc. Int. Congr. Math., Vol. I, 1950.

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Acta Szeged, Hungary, *XIIB*, 1-15, 1950.

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Fourier Series, Lattice Points and Watson Transforms
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J. Ind. Math. Soc., *XV*, Part A, 1951.

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Am. J. Math., *73*, 233-255, 1951.

1952

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A Quasi-Tauberian Theorem on Fourier Series
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Algebraic Basis of Morse's Variational Theory in the Large
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J. Ind. Math. Soc., *XIX*, 31-60, 1955.

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Sur l'Equation Fonctionnelle de Riemann
C.R. Acad. Sci., Paris, *242,* 2793-2796, 1956.

NARASIMHAN, M.S.
The Problem of Limits on a Riemannian Manifold
J. Ind. Math. Soc., *XX,* 291-297, 1956.

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Quadratic Forms Over Involutorial Division Algebras
J. Ind. Math. Soc., *20,* 227-257, 1956.

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Units of Fixed Points in Involutorial Algebras
Proc. Int. Symp. Algebraic Number Theory, Tokyo, 103-106, 1956.

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Seminars on Analytic Functions, *I,* 1-36,1957.

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J. Ind. Math. Soc., *21,* 149-170, 1957.

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C.R. Acad. Sci., Paris, *251*, 1333-1335, 1960.

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Annales de l'Inst. Fourier, *10*, 285-296, 1960.

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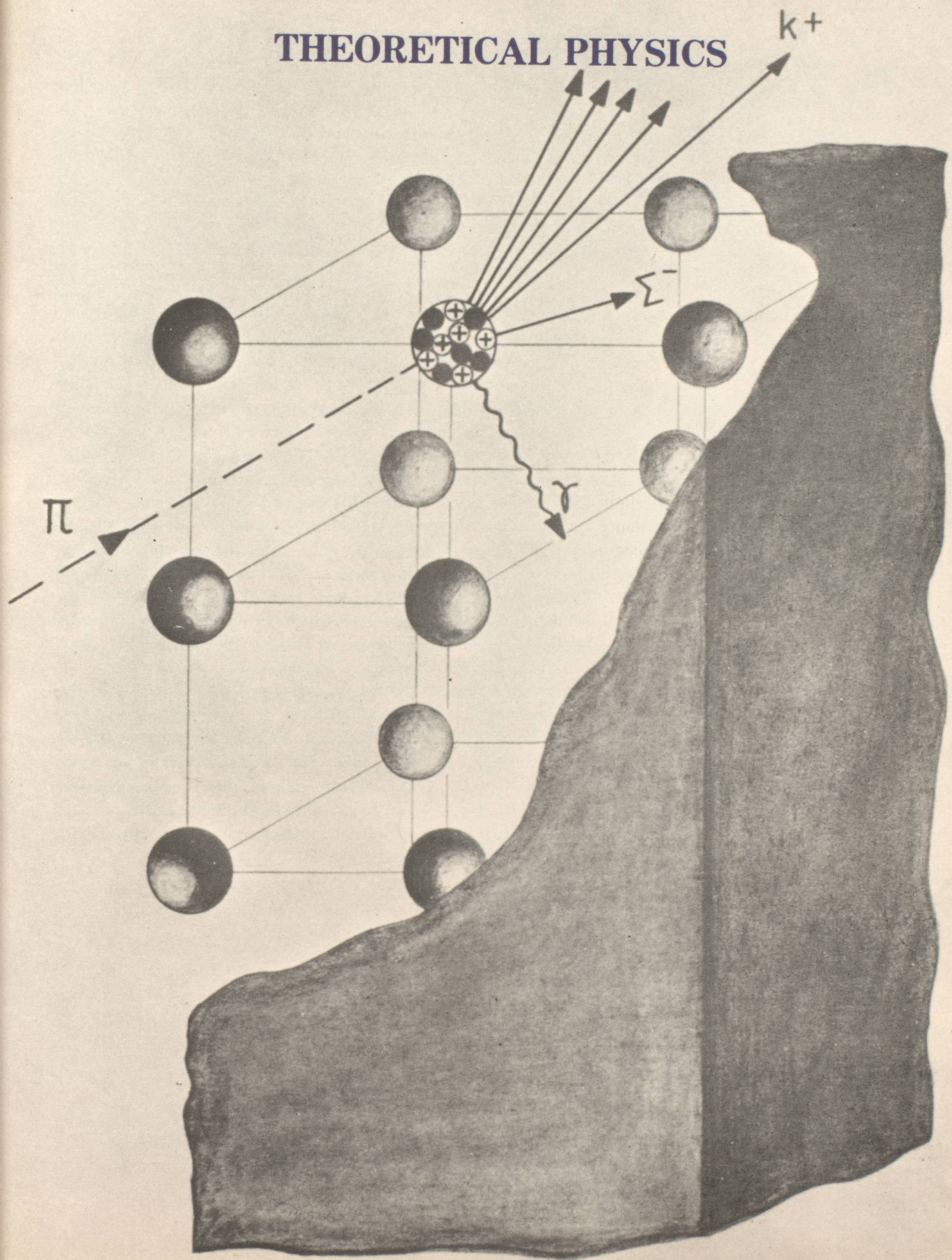
Visiting Mathematicians

1946-47	S.S. CHERN	U.S.A.
	L.J. MORDELL	U.K.
	J. HADAMARD	France
1949	M.H. STONE	U.S.A.
1951-52	HARISH-CHANDRA	U.S.A.
	C. RACINE	India
	S. MINAKSHISUNDARAM	India
1953-54	W. AMBROSE	U.S.A.
	H. MAASS	Germany
	H. RADEMACHER	U.S.A.
	N. WIENER	U.S.A.
1955	M. EICHLER	Germany
	L. SCHWARTZ	France
	C.L. SIEGEL	Germany
	M.H. STONE	U.S.A.
1956	A.D. ALEXANDROV	U.S.S.R.
	E. BOMPIANI	Italy
	C.H. DOWKER	U.K.
	Y.N. DOWKER	U.K.
	Ch. EHRESMANN	France
	S. EILENBERG	U.S.A.
	S. MANDELBROJT	France
	P. TURAN	Hungary
	K. YOSIDA	Japan
	O. ZARISKI	U.S.A.
1957	J.P. KAHANE	France
	J.L. LIONS	France
	H.R. PITT	U.K.
	L. SCHWARTZ	France
1958	F. BRUHAT	France
	M. DEURING	Germany
	W.K. HAYMAN	U.K.
	K. ITO	Japan
	B. MALGRANGE	France
1959	R. BRAUER	U.S.A.
	M. BRELOT	France
	J.C. BURKILL	U.K.
	J. DELSARTE	France
	J.L. KOSZUL	France
	M. KURANISHI	Japan
	A. NERON	France
	B.H. NEUMANN	U.K.
	M.H.A. NEWMAN	U.K.
	C.L. SIEGEL	Germany

1960	R. KAWAI	Japan
	S.L. SOBOLEV	U.S.S.R.
1961	W.L. BAILY, Jr.	U.S.A.
	F.F. BONSALL	U.K.
	A. BOREL	U.S.A.
	F. BRUHAT	France
	A.E. INGHAM	U.K.
	M. NAGATA	Japan
1962	A. ANDREOTTI	Italy
	H. CARTAN	France
	M. HERVE	France
	H. MAASS	Germany
	S. MIZOHATA	Japan
	C.L. SIEGEL	Germany
1963	J. DIEUDONNE	France
	E. HILLE	France
	J.L. KOSZUL	France
	Y.V. LINNIK	U.S.S.R.
	P. SAMUEL	France
	A. VAN de VEN	Netherlands
1964	M. BERGER	France
	B. CENKL	Czechoslovakia
	B. MALGRANGE	France
	S. NAKANO	Japan
	J.P. MURRE	Netherlands
1965-66	H. BASS	U.S.A.
	O. FROSTMAN	Sweden
	N.H. KUIPER	Netherlands
	S.N. MERGUELIAN	U.S.S.R.
	I.R. SHAFAREVICH	U.S.S.R.
	L. SCHWARTZ	France
	M.H. SCHWARTZ	France
	J.F. TREVES	France
	E. VESENTINI	Italy
	G. de RHAM	Switzerland
	P. GABRIEL	France
	M.A. KERVAIRE	U.S.A.
	A. PFLUGER	Switzerland
	P. SAMUEL	France
	C.L. SIEGEL	Germany
	J.R. STALLINGS	U.S.A.
1967	V. ARNOLD	U.S.S.R.
	B.A. BARNES	U.S.A.
	M. KNESER	Germany
	D. MUMFORD	U.S.A.
	T.A. SPRINGER	Netherlands
1968	B.J. BIRCH	U.K.
	A. BOREL	U.S.A.
	H. KLINGEN	Germany
	Yu.I.MANIN	U.S.S.R.
	J.L. VERDIER	France
	A. WEIL	U.S.A.

1969	S.S. ABHYANKAR	U.S.A.
	H. BASS	U.S.A.
	HEL BRAUN	Germany
	R. HARTSHORNE	U.S.A.
	N. JACOBSON	U.S.A.
	M.A. KERVAIRE	U.S.A.
	G.D. MOSTOW	U.S.A.
	M. OJANGUREN	Switzerland
	D.P. ROLFSEN	U.S.A.
	Th. SCHNEIDER	Germany
	SHANKER SEN	U.S.A.
1970	M. DEMAZURE	France
	E.R. KOLCHIN	U.S.A.
	B. KOSTANT	U.S.A.
	G.W. MACKEY	U.S.A.
	S. MURAKAMI	Japan

THEORETICAL PHYSICS



THEORETICAL PHYSICS

General

Interest in Theoretical Physics at the TIFR is as old as the Institute itself. This is not surprising, considering that Dr. Bhabha, in his letter dated 12th March 1944 to Sir Sorab Saklatvala, of the Sir Dorabji Tata Trust, proposing the setting up of the Institute, had stated, " the subjects on which research and advanced teaching would be done would be theoretical physics, especially on fundamental problems and with special reference to cosmic rays and nuclear physics...." The importance of developing a strong school of modern Theoretical Physics, where the principal concern would be with the basic theoretical understanding of physical phenomena, and one of whose tasks would also be to provide theoretical assistance and guidance to experimental programmes, was thus realised from the beginning. During the fifties, this group provided the core of the Reactor Theory Group for the country's atomic energy programme in its initial stages. In more recent years, the group has grown into a powerful, broad-based group, with about 30 members (exclusive of graduate students), whose research interests cover three major fields: (i) Particle Physics; (ii) Nuclear Physics; and (iii) Solid State Physics. It is the foremost Theoretical Physics Group in the country in size, breadth of activities and number of recognized scientists, and is also known for its various contributions internationally. A total of about 500 papers have been published in various journals and proceedings of Conferences and Symposia, by members of the group, and 19 Ph. D. theses have been written so far, based on the work carried out in the group. About 70% of these publications and theses were completed during the last six years. The development of the research activity is seen from the list of publications and theses appended to this report. Only the broad features are discussed below.

The history of the development of the Theoretical Physics Group may be considered roughly in the following four phases:

The early period	1945-53
The period	1953-58
The period	1958-63
The present period	1963-70.

Early Work

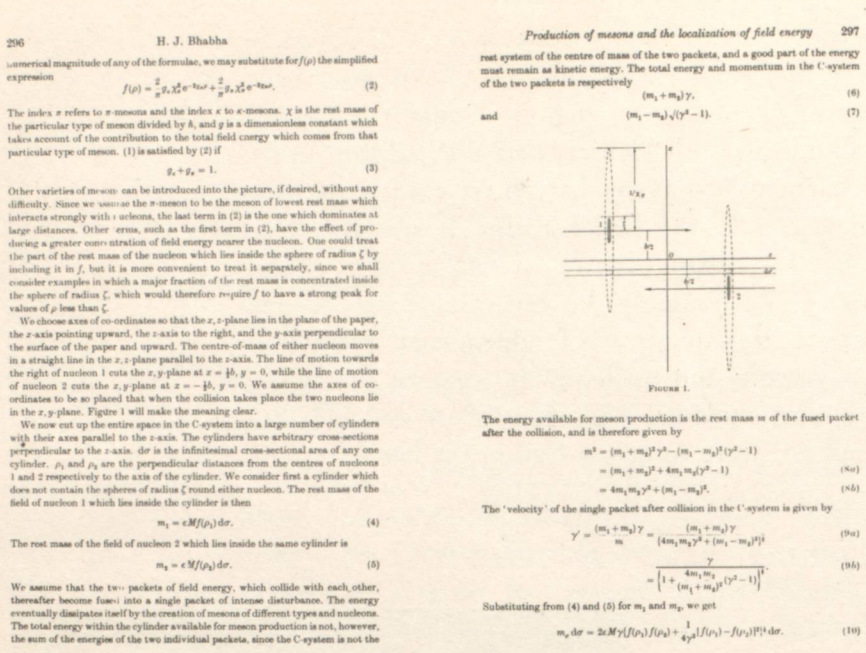
Research activity during the first period was almost entirely dominated by the personal work of Dr. Bhabha, and was principally in the field of Elementary Particles. Around the year 1945, one of the burning questions in particle physics

concerned the nature of the meson, which had been postulated by Yukawa in 1935 as the mediator of nuclear force, but had yet to be discovered experimentally. Bhabha's earlier work on penetrating cosmic ray showers, using the cascade theory developed by him in collaboration with Heitler, had also led him to see the necessity of assuming that a particle of intermediate mass existed in these showers, and in fact the name meson was suggested by him. It was therefore natural that during the early years, Dr. Bhabha, in collaboration with a few associates, actively pursued the theory of cosmic ray showers, meson production, and nuclear forces. He also attacked the question of appropriate relativistic quantum mechanical description of mesons and nucleons. In some of this work, he was assisted by half a dozen young students, who were thus initiated into theoretical research, and some of whom were to take a lead in the later development of the group.



Fig. 1—P.A.M.Dirac and Homi Bhabha.

The principal contributions during this period were Bhabha's extension of the Fermi Theory of meson production in high energy collisions, and his ambitious attempt to develop a postulational basis for the theory of elementary particles. In the course of this work he investigated a class of relativistic linear wave equations, which were capable of describing a particle having states with different masses and spins. Such equations have also been reinvestigated in recent years, following the discovery of large numbers of particles and resonances during the last decade.



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numerical magnitude of any of the formulae, we may substitute for $f(\rho)$ the simplified expression

$$f(\rho) = \frac{\hat{g}}{\pi} g_\pi \chi_\pi^2 e^{-2\chi_\pi \rho} + \frac{\hat{g}}{\pi} g_\kappa \chi_\kappa^2 e^{-2\chi_\kappa \rho}. \quad (2)$$

The index π refers to π-mesons and the index κ to κ-mesons. χ is the rest mass of the particular type of meson divided by $\hbar$, and g is a dimensionless constant which takes account of the contribution to the total field energy which comes from that particular type of meson. (1) is satisfied by (2) if

$$g_\pi + g_\kappa = 1. \quad (3)$$

Other varieties of meson can be introduced into the picture, if desired, without any difficulty. Since we assume the π-meson to be the meson of lowest rest mass which interacts strongly with nucleons, the last term in (2) is the one which dominates at large distances. Other terms, such as the first term in (2), have the effect of producing a greater concentration of field energy nearer the nucleon. One could treat the part of the rest mass of the nucleon which lies inside the sphere of radius ζ by including it in f, but it is more convenient to treat it separately, since we shall consider examples in which a major fraction of the rest mass is concentrated inside the sphere of radius ζ, which would therefore require f to have a strong peak for values of ρ less than ζ.

We choose axes of co-ordinates so that the x, z-plane lies in the plane of the paper, the x-axis pointing upward, the z-axis to the right, and the y-axis perpendicular to the surface of the paper and upward. The centre-of-mass of either nucleon moves in a straight line in the x, z-plane parallel to the z-axis. The line of motion towards the right of nucleon 1 cuts the x, y-plane at $x = \frac{1}{2}b$, $y = 0$, while the line of motion of nucleon 2 cuts the x, y-plane at $x = -\frac{1}{2}b$, $y = 0$. We assume the axes of co-ordinates to be so placed that when the collision takes place the two nucleons lie in the x, y-plane. Figure 1 will make the meaning clear.

We now cut up the entire space in the C-system into a large number of cylinders with their axes parallel to the z-axis. The cylinders have arbitrary cross-sections perpendicular to the z-axis. $d\sigma$ is the infinitesimal cross-sectional area of any one cylinder. ρ_1 and ρ_2 are the perpendicular distances from the centres of nucleons 1 and 2 respectively to the axis of the cylinder. We consider first a cylinder which does not contain the spheres of radius ζ round either nucleon. The rest mass of the field of nucleon 1 which lies inside the cylinder is then

$$m_1 = \epsilon M f(\rho_1) d\sigma. \quad (4)$$

The rest mass of the field of nucleon 2 which lies inside the same cylinder is

$$m_2 = \epsilon M f(\rho_2) d\sigma. \quad (5)$$

We assume that the two packets of field energy, which collide with each other, thereafter become fused into a single packet of intense disturbance. The energy eventually dissipates itself by the creation of mesons of different types and nucleons. The total energy within the cylinder available for meson production is not, however, the sum of the energies of the two individual packets, since the C-system is not the

Production of mesons and the localization of field energy 297

rest system of the centre of mass of the two packets, and a good part of the energy must remain as kinetic energy. The total energy and momentum in the C-system of the two packets is respectively

$$(m_1 + m_2)\gamma, \quad (6)$$

and

$$(m_1 - m_2)\sqrt{(\gamma^2 - 1)}. \quad (7)$$

FIGURE 1.

The energy available for meson production is the rest mass m of the fused packet after the collision, and is therefore given by

$$m^2 = (m_1 + m_2)^2\gamma^2 - (m_1 - m_2)^2(\gamma^2 - 1)$$
$$= (m_1 + m_2)^2 + 4m_1 m_2(\gamma^2 - 1) \quad (8a)$$
$$= 4m_1 m_2\gamma^2 + (m_1 - m_2)^2. \quad (8b)$$

The 'velocity' of the single packet after collision in the C-system is given by

$$\gamma' = \frac{(m_1 + m_2)\gamma}{m} = \frac{(m_1 + m_2)\gamma}{\{4m_1 m_2\gamma^2 + (m_1 - m_2)^2\}^{\frac{1}{2}}} \quad (9a)$$
$$= \frac{\gamma}{\left\{1 + \frac{4m_1 m_2}{(m_1 + m_2)^2}(\gamma^2 - 1)\right\}^{\frac{1}{2}}}. \quad (9b)$$

Substituting from (4) and (5) for m_1 and m_2, we get

$$m_\sigma d\sigma = 2\epsilon M\gamma\{f(\rho_1) f(\rho_2) + \frac{1}{4\gamma^2}|f(\rho_1) - f(\rho_2)|^2\} d\sigma. \quad (10)$$

Fig. 2—From Homi Bhabha's last research paper: "The Production of Mesons and the Localisation of Field Energy", Proceedings of the Royal Society (219A, 293-303, 1953).

Elsewhere during this period, important developments were taking place in the field of Quantum Electrodynamics. One notices that the group did not make any contribution to these—an effect on a small group, of isolation from other active centres in the world.

The period 1953-58

The output of the Group dropped considerably during the next period (1953-58), as Dr. Bhabha got involved in the growth of the Indian Atomic Energy Programme, and some of the other members were also drafted into this programme. The Theoretical Physics Group of the Atomic Energy Establishment

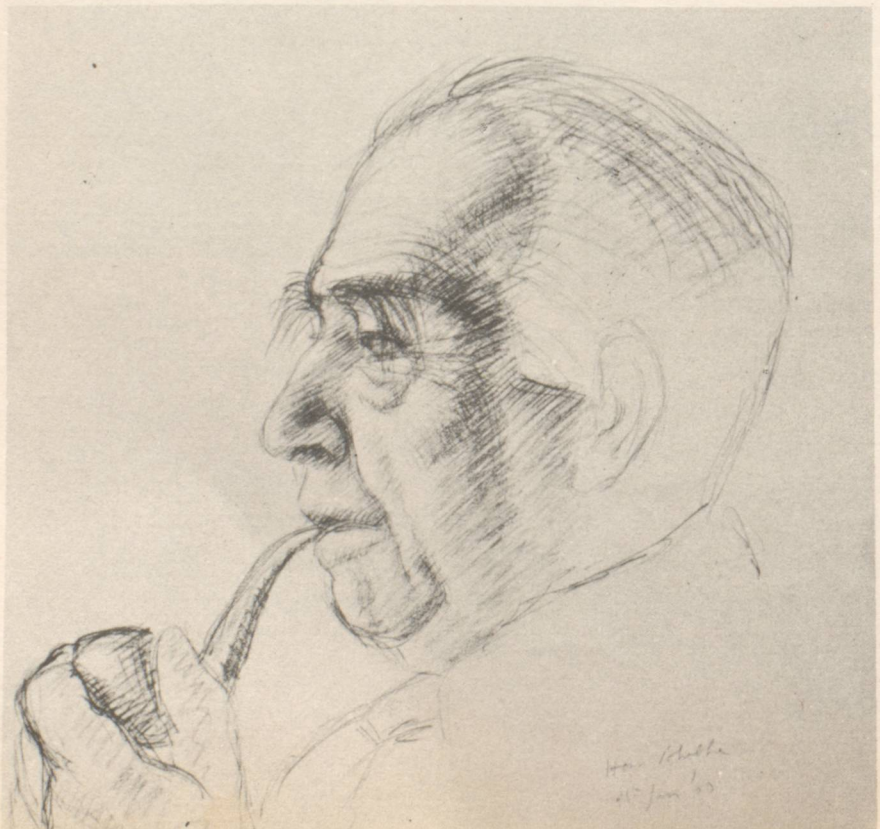


Fig. 3—A pencil sketch of Niels Bohr by Homi Bhabha.

was essentially a part of the Theoretical Physics Group of the Institute until 1960, and many of the present senior members of the Reactor Theory Group at Trombay received their early training in TIFR during this period. With some new members joining, the group saw some diversity in activity. For example, the first papers in Solid State Physics and Nuclear Physics appeared during this period. The work on extensive air showers continued. The interest in elementary particles also continued. Apart from the work represented by publications of this period, the exciting developments in strange particle physics and those leading to fall of parity, developments in many-body theory, etc. were also being followed closely through series of seminars and colloquia. However, the group had not yet developed a viable critical strength to be able to contribute to these developments.

Activities during 1958-63

Towards the end of the above period, several new members joined the group, either as students or as post-doctoral research fellows. A large increase in the yearly publications followed during the next period (1958-63), showing that a new stage had been reached in its development. One also sees a greater diversity in the subjects of investigations: nuclear model calculations, nuclear many-body problem, boson-gas, acceleration mechanism for cosmic radiation, stability and other problems in magnetohydrodynamics and hydromagnetic turbulence, neutron scattering, and various problems in the strong, electromagnetic and weak interactions of elementary particles and their symmetries. A large fraction of the publications were in the area of particle physics. It is clear that members were developing competence in new techniques and a confidence in applying them to a variety of problems, and trying to get into the mainstream of international research developments.

Fig. 4—Group photograph of the participants: Summer School in Theoretical Physics organised by the Institute at Bangalore in 1961. The principal lecturers were R.H.Dalitz and M. Gell-Mann. This was the first in the series of Summer Schools that are now regularly orgainsed by the Institute on a variety of subjects every year.



Two new activities, which have played an important part in later developments, were initiated during this period. Firstly, the Atomic Energy Training School Programme was started, and it drew quite substantially upon the members of the Institute, of the Theory Group in particular, for teaching purposes. It also began providing a rich source of talent for strengthening the group.

The other activity which has proved even more important, both for the Institute as well as for the development of Theoretical Physics in the country at large, was the start made in organizing Summer Schools in Theoretical Physics. The first of these was held in 1961 at Bangalore, and had Prof.M. Gell-Mann and Prof.R.H.Dalitz as lecturers at a very critical period in Particle Physics when new ideas on symmetries and phenomenology were being developed. This series of summer schools has proved to be of great value in the training of theoretical physicists in the Institute and elsewhere in the country, besides removing the sense of isolation from other active centres in the world.

Along with these activities, there gradually evolved a well-phased programme of selecting bright students, giving them a preliminary training for a couple of years at the Institute and then placing them, as well as some of the more senior members, abroad for doctoral and post-doctoral research at some of the leading centres in the world. When they started coming back towards the end of this period, one had within a single group young theoreticians who had been trained in, or been exposed to, a wide spectrum of leading schools in the world. Moreover, some members started making significant contributions, either here or during their leave of absence abroad. Among these may be mentioned the work on electromagnetic properties of superconductors, the work on analyticity in the complex angular momentum plane and high energy phenomenology based on it, and the work on the transverse momentum damping in high energy scattering.

This period was thus the time when the group went through a slow maturing process, its members started getting international recognition for some of their contributions, and its strength started becoming critical and viable. This happened first in Particle Physics, and other areas were soon to follow.

Current Programmes

The more recent phase (1963-70) is marked by a very high level of research activity, comparable with that in any other major centre in the world.

In *Particle Physics,* the Group covers a very wide spectrum of activities, and areas in which members have made significant contributions include:

(i) S-matrix theory and field theory; bootstraps; strong coupling theory; bounds on cross-sections arising from general constraints of analyticity, unitarity and crossing;
(ii) High energy scattering, using Regge poles and other phenomenological models;

(iii) Symmetries of strongly interacting particles: SU(3); SU(6); non-compact groups;

(iv) Infinite component wave equations;

(v) Current algebra: sum rules and representation theory; chiral symmetries;

(vi) Weak interactions: CP-violation; symmetry-breaking effects; higher order weak interactions;

(vii) Electromagnetic interactions: electromagnetic self-masses; exact low energy theorems; electro-production and photo-production at high energies.

One notes the breadth of coverage in this area, almost all the points of the expanding frontier being covered with a high degree of competence by the Group. It is hoped to achieve a similar coverage in other areas too in the near future.

In *Nuclear Physics* the Group's principal contributions have been in the following fields:

(i) Problems of Nuclear Structure from the many-body theory point of view: the problems investigated concern effective nucleon-nucleon interaction, spherical and deformed Hartree-Fock theory, Generator coordinate method, equation of motion and Random-Phase-Approximation methods, application of group theoretical techniques.

(ii) Nuclear Reactions: statistical hypothesis has been used in compound nucleus reactions; large momentum transfer direct reactions and low energy nucleon scattering have been studied.

In *Solid State Physics,* the interest has been mainly concentrated on

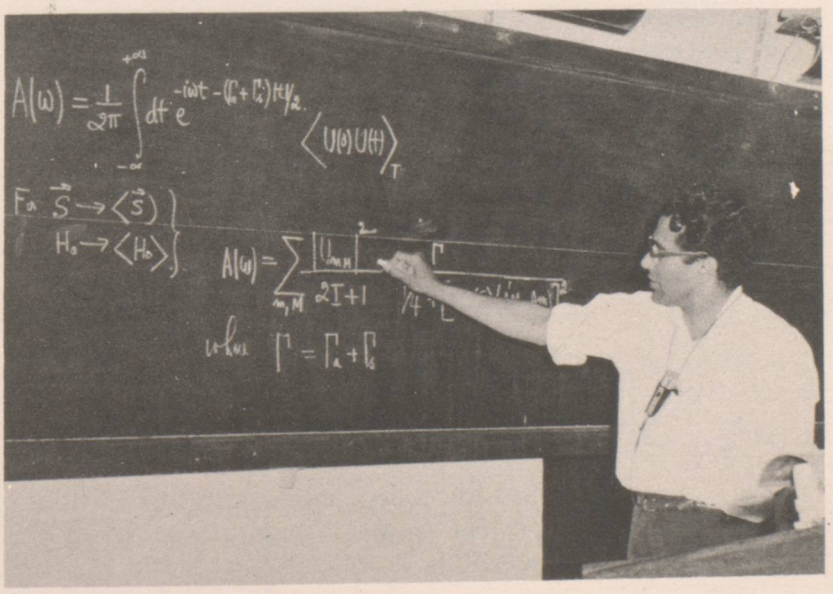


Fig. 5—K.S.Singwi lecturing at the Bangalore Summer School (1968).

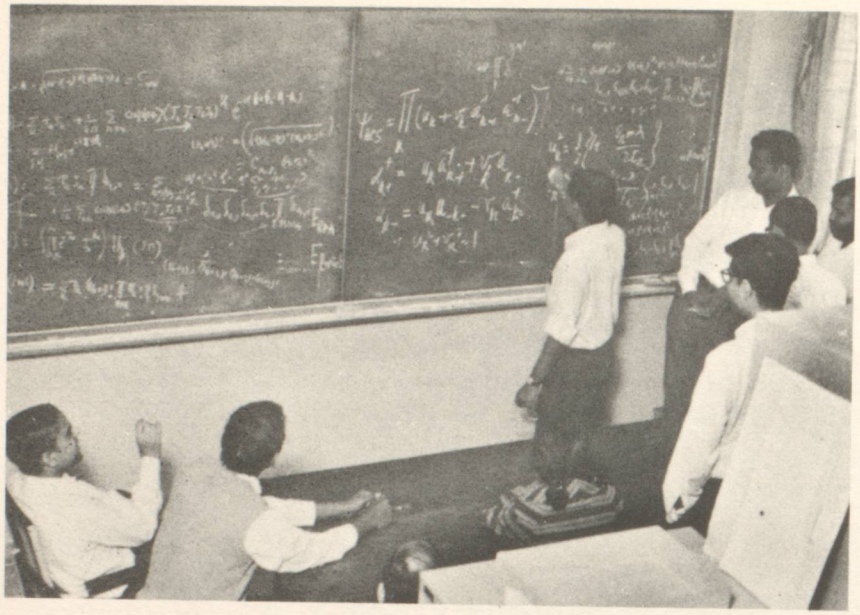


Fig. 6—An informal discussion in the Seminar Room.

(i) Linear and nonlinear optical properties of solids; electronic and phonon Raman scattering;
(ii) Positron annihilation in solids;
(iii) Electronic band structure calculations;
(iv) Heisenberg Hamiltonian in magnetism;
(v) Theory of phase transitions;
(vi) Superconductivity;
(vii) Quantum fluids.

Other interests have been semi-conductor physics and the three-body problem in the Fadeev formalism.

Educational Programmes

As the group grew in strength, it was natural for it to make a contribution to the development of various educational programmes. In earlier years, when the Institute was small, it could not offer many formal courses to its Ph.D. students, though there were always a few courses every year, some given by its own members, and some by visiting foreign scientists. Thus courses by distinguished visiting scientists like Alfvèn, Dirac, Pauli, Rosenfeld, Serber, Wentzel filled part of the gap with regard to graduate courses. Since 1964, however, a regular graduate course programme has been gradually evolved at the Institute, aimed at making the Ph.D. training more and more systematic and broad-based. The theoretical physics group has taken a leading part in developing this programme. Members of the group have also been actively involved in developing various educational programmes at the University of Bombay. These include participation in lectures to the M.Sc. students, modernization of the M.Sc. syllabus, discussion groups for college teachers and bright undergraduates, etc. Many of them have also given courses at summer schools and refresher programmes organised elsewhere in the country.

THEORETICAL PHYSICS

Papers Published in Scientific Journals

1945

BHABHA, H.J.
Relativistic Wave Equations for the Proton
Proc. Ind. Acad. Sci., *21A*, 241, 1945.

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Curr. Sci., *14*, 98, 1945.

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1946

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Rep. Prog. Phys., *10*, 253, 1946.

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1948

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1949

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Phys. Rev., *77*, 665, 1950.

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Proc. Roy. Soc., *202A*, 301, 1950.

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Proc. Ind. Acad. Sci., *31*, 240, 1950.

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Stars and Single Tracks in Nuclear Plates
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1951

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On a Class of Relativistic Wave Equations of Spin 3/2
Proc. Ind. Acad. Sci., *34A*, 335, 1951.

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1952

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Phil. Mag., *43*, 33, 1952.

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1953

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RUSTAGI, K. C.
Nonlinear Optical Susceptibilities of Semiconductors
Bombay University, 1970, Ph.D.

SINGH, Y.
Some Investigations on the Semi-Leptonic and Weak-Radiative Decays of Hadrons
Bombay University, 1970, Ph.D.

COSMIC RADIATION



A giant unleashed, the hydrogen filled polyethylene balloon leaps skywards when released from its restraining clamp.

COSMIC RADIATION

The discovery of cosmic rays

More than 150 years ago, the French physicist Coulomb showed that a metal sphere suspended in air by silk threads gradually lost any charge given to it. Allowing for a small loss of charge along the silk threads, he concluded that there must be a leakage through the air itself, though it was known that air is a bad conductor. When the phenomenon of radioactivity was discovered towards the end of the 19th century, the conductivity of air near the ground was attributed to it. But during the years just prior to World War I, the Austrian physicist Hess, carried up instruments in person on balloons and found that the conductivity of air rapidly increased with increasing altitude. This suggested that the conductivity was due to some radiation which came in from outside the earth. This was later confirmed and the radiation responsible was named the *Cosmic Radiation* by Millikan in 1925. For this discovery Hess received the Nobel Prize for Physics in 1936.

Scope of cosmic ray research

Since the discovery by Hess, we have gone a long way in our knowledge concerning the cosmic radiation. We now know that cosmic rays are particulate matter, such as atomic nuclei and electrons, which move with great energies in the spaces between the stars of our galaxy; it seems very likely that they exist also in other galaxies, and even in the voids between galaxies. They are thought to originate in explosive processes that occur in stars, such as in novae and supernovae, and in galaxies; it is speculated that their origin also lies in the newly discovered pulsars, which are considered to be dense neutron stars. Nearer our planet, we have conclusive evidence that cosmic rays are produced in a limited way during times of great flares on the surface of the sun. Since cosmic space is not empty, but is pervaded by tenuous gas clouds, weak magnetic fields and radiation fields, the cosmic rays during their traversal through this space interact with these forms of matter and energy, and give rise to secondary forms of particle and electromagnetic radiations; the latter manifest themselves as radio, infra-red, visible, X-ray or gamma radiation of cosmic origin. It is known that cosmic ray energies extend to as high a value as 10^{20} eV — which is a thousand million times larger than the energies to which particles can be accelerated artificially on earth. Work on the origin, history and interactions of cosmic radiation thus covers the domains of astrophysics, cosmology, high energy physics, nuclear physics, magnetohydrodynamics and plasma physics.

It should be particularly emphasised that the particulate cosmic radiation is the only sample of matter from outside the solar system which is accessible to direct human experimentation.

Genesis of cosmic ray studies at the Institute

Cosmic ray physics has been one of the major areas of research at the Institute since it was founded in 1945. This is not surprising considering that Homi Bhabha's early major scientific contributions were in this field: the Bhabha-Heitler cascade theory, and then the analysis of penetrating showers which led to the conclusion that there existed, in the cosmic ray beam, mesons with a mass intermediate between that of the electron and the proton. Homi Bhabha was fully conscious of the scope and potentiality for development of the subject, particularly from the viewpoint of high energy elementary particle physics. In fact, in his letter dated March 12, 1944 to the Sir Dorabji Tata Trust, proposing the setting up of the Tata Institute of Fundamental Research he wrote "the subjects on which research and advanced teaching would be done would be theoretical physics, especially on fundamental problems with special reference to cosmic rays and nuclear physics, and experimental research on cosmic rays".

Advantages for cosmic ray research in India

It is well-known that the charged cosmic ray particles entering the vicinity of the earth are influenced by the terrestrial magnetic field. And only the energetic part of the radiation is able to reach the upper reaches of the atmosphere over India, since it is located at low geomagnetic latitudes where the effect of the magnetic field is maximum; this provides the possibility of studying over India, the high energy part of the radiation without the background of the low energy component. It also provides special advantages for detecting and studying neutral radiations such as cosmic X-rays, gamma rays and solar neutrons since the low energy charged particle radiation if filtered out and consequently the background it would otherwise have created is not there. A further advantage lies in the fact that certain parts of the sky can be favourably studied that are not conveniently seen from elsewhere.

Recognising these advantages, the Institute has built up an independent capability to make high altitude balloon ascents to carry cosmic ray instruments to great altitudes; this is essential in order to sample the primary radiations before they get modified in traversing the earth's atmosphere. Such flights were made with rubber balloons until about 1955. Thereafter, because of the need to carry heavy loads to very high altitudes, and to keep these in level flight for extended periods of times, the plastic balloon technique was developed. Since 1960 constant volume polyethylene balloons have been successfully fabricated in the Institute and flown from Hyderabad for cosmic ray research.

The existence in the country of very deep mines, (in the Kolar Gold Fields in South India), which go down to depths of over two miles below the earth's surface has been recognised as a unique facility for carrying out a wide range of

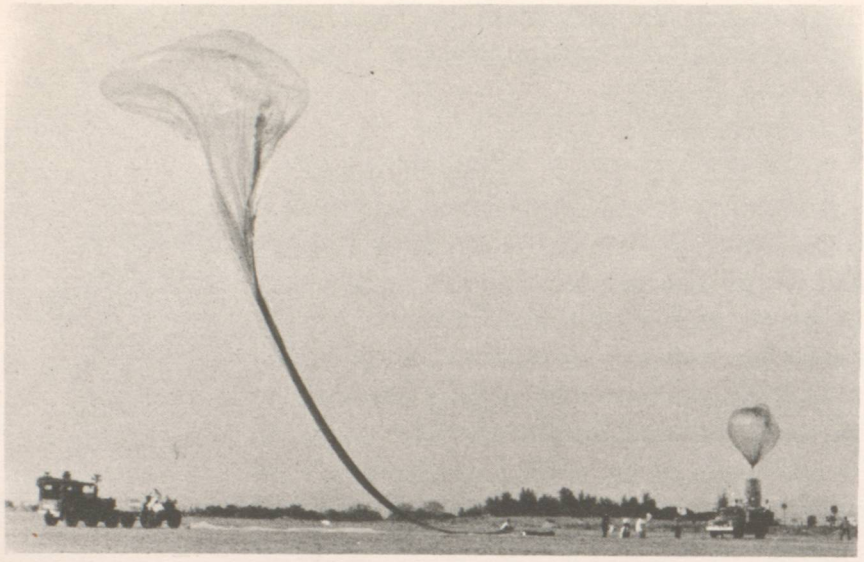


Fig. 1—Action picture of a balloon launch just at the time when the hydrogen filled bubble is released. The extended lower part of the balloon, the parachute, auxilliary instrumentation on the load line, and at the end of the long line, the main instrument resting on the launch vehicle, can all be seen. The vehicle is manoeuvred such that the main instrument is directly below when the entire train sweeps into a vertical configuration; and at this point the instrument is released.

experiments on the very penetrating secondary cosmic ray components: the high energy muons and the neutrinos. Also at Kolar it has been possible to perform air shower experiments at the surface along with observations on associated high energy muons detected deep underground; these studies cannot be easily carried out elsewhere.

All of these natural advantages have been recognised, and made full use of, resulting in a high tempo of cosmic ray research since 1947. The cosmic ray group at the Institute has now grown to be one of the very large ones in the world, with perhaps the greatest variety of investigations performed by any single such group.

Status of cosmic ray research in the late 1940's

Historical development

A great upsurge in cosmic ray research occurred during the late 1940's when research programmes in this area were just being initiated in the Institute. The mu-meson, (intermediate in mass between the electron and the proton), and the positron, (the anti-particle of the electron and the first of the anti-particles to be observed), had already been discovered in the 1930's as a result of cosmic ray studies. Immediately after the Second World War it was shown that the mu-meson was not the particle hypothesised by Yukawa to explain the forces that hold the nucleus together. In 1947, the pi-meson, a strongly interacting meson, which appeared to fulfil all the requirements of the Yukawa hypothesis, was discovered by Powell and his colleagues in Bristol, using nuclear emulsions exposed to cosmic rays; also, evidence was obtained the same year for the existence of still heavier unstable particles, by Rochester and Butler carrying out cosmic ray studies in Manchester using cloud chambers; and soon after, decisive evidence concerning the existence of such particles was obtained in nuclear emulsion studies carried out at Bristol by Powell and his colleagues. In the United States, Peters and his collaborators discovered in 1948 the existence of



Fig. 2—During one of his visits to the Institute, Prof. Cecil Powell of Bristol University having an amusing conversation with Dr. Homi Bhabha.

heavy nuclei in the primary cosmic radiation. This was the exciting state of cosmic ray physics in the late 1940's.

Having himself carried out pioneering work in the field of cosmic radiation, Homi Bhabha was quick to realise and to foresee the immense long term possibilities of these new discoveries; the result was the commitment of the Institute to undertake a long-term programme of cosmic ray research. Three major technique-oriented groups were planned based on the use of nuclear emulsions, cloud chambers and electronic detector systems for high altitude studies.

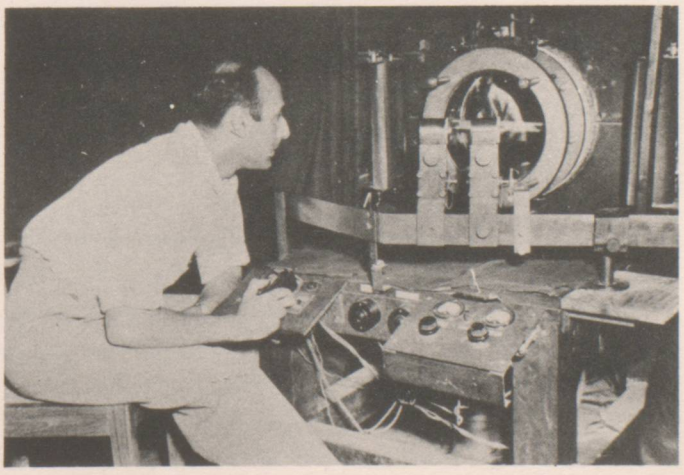


Fig. 3—The beginning of cosmic ray research in 1947 with the 12-inch diameter cloud chamber in operation.

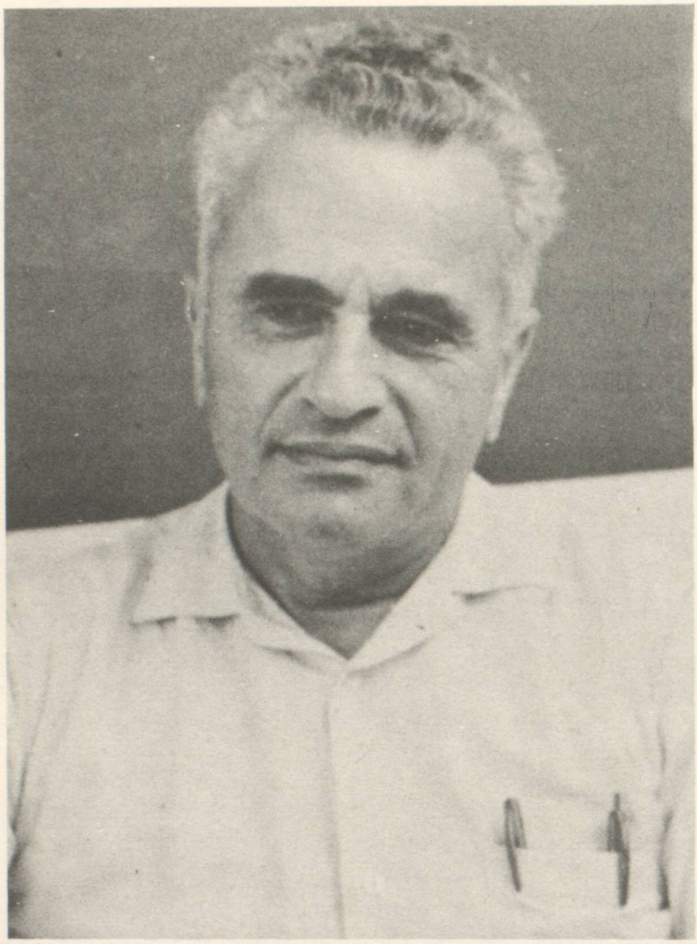


Fig. 4 Bernard Peters
Honorary Fellow of the Institute

Early work in this field was of a phenomenological nature: studies with a 12″ cloud chamber operated at sea level, and with nuclear emulsions and electronic detector systems sent up on rubber balloons to altitudes of up to about 80,000 ft.

Development of cosmic ray research at the Institute

Following the balloon expendition jointly organised by the Institute and the University of Rochester, USA in 1950-1951, Prof. B. Peters joined the Institute in 1952 and was a staff member until 1959; during this period some of the important directions of cosmic ray research were defined and established under his leadership.

In 1952-1953, a major breakthrough was the successful development of the stripped emulsion technique in the Institute, contemporaneous with similar work in Bristol and in Washington; as a result of this, important discoveries were made in the field of strange particle physics, which then was the most exciting frontier in particle physics. Other interesting work carried out using the nuclear emulsion technique pertained to high energy nuclear interactions and the chemical composition of the primary radiation.

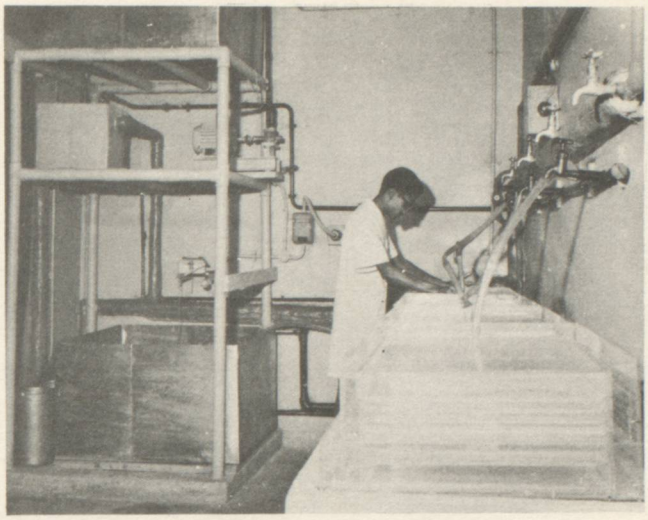


Fig. 5—Specially designed dark room to process nuclear emulsion stacks of large volume. The entire process, including development and fixing, takes about 10 days under controlled temperature conditions.

In 1955 it was recognised that, with the advent of high energy accelerators in the GeV energy region, work relating to elementary particles would largely be carried out with beams of artificially accelerated high energy particles. It was therefore decided not to continue with the type of nuclear emulsion work on particle physics that had yielded rich dividends over the years 1951-1954. Instead the emphasis was shifted: to studies of the primary cosmic radiation that would be of astrophysical interest; to studies of high energy interactions beyond the energy range of accelerators; to studies of extensive air showers; to studies of high energy muons; and to geophysical and astrophysical studies based on the use of cosmic ray produced radioisotopes as tracers.

Towards this objective, over the period 1955-1960, a sustained effort was made to fabricate and launch constant volume polyethylene balloons of great volume. For work on the primary cosmic radiation it was essential to float instrumented loads for extended periods of times at altitudes in excess of 100,000ft., corresponding to a residual air mass less than 1% of the normal atmospheric pressure (at sea level). With the successful development of this technological capability it became possible to exploit fully the location of India close to the geomagnetic equator for investigations on electrons, X-rays, gamma rays and the nucleonic component of the primary cosmic radiation.

It was recognised during the early 1950's, that the deep mines in the Kolar Gold Fields (KGF) could be used profitably for studies on cosmic ray produced mu-mesons; and experiments were then carried out in these mines up to depths of about 1000 ft. Later, such investigations were continued in an unused railway tunnel at Khandala, near Bombay. Then, for several years, this area of studies, on high energy cosmic ray muons, was discontinued whilst major experimental programmes relating to extensive air showers and high energy interactions were taken in hand and established.

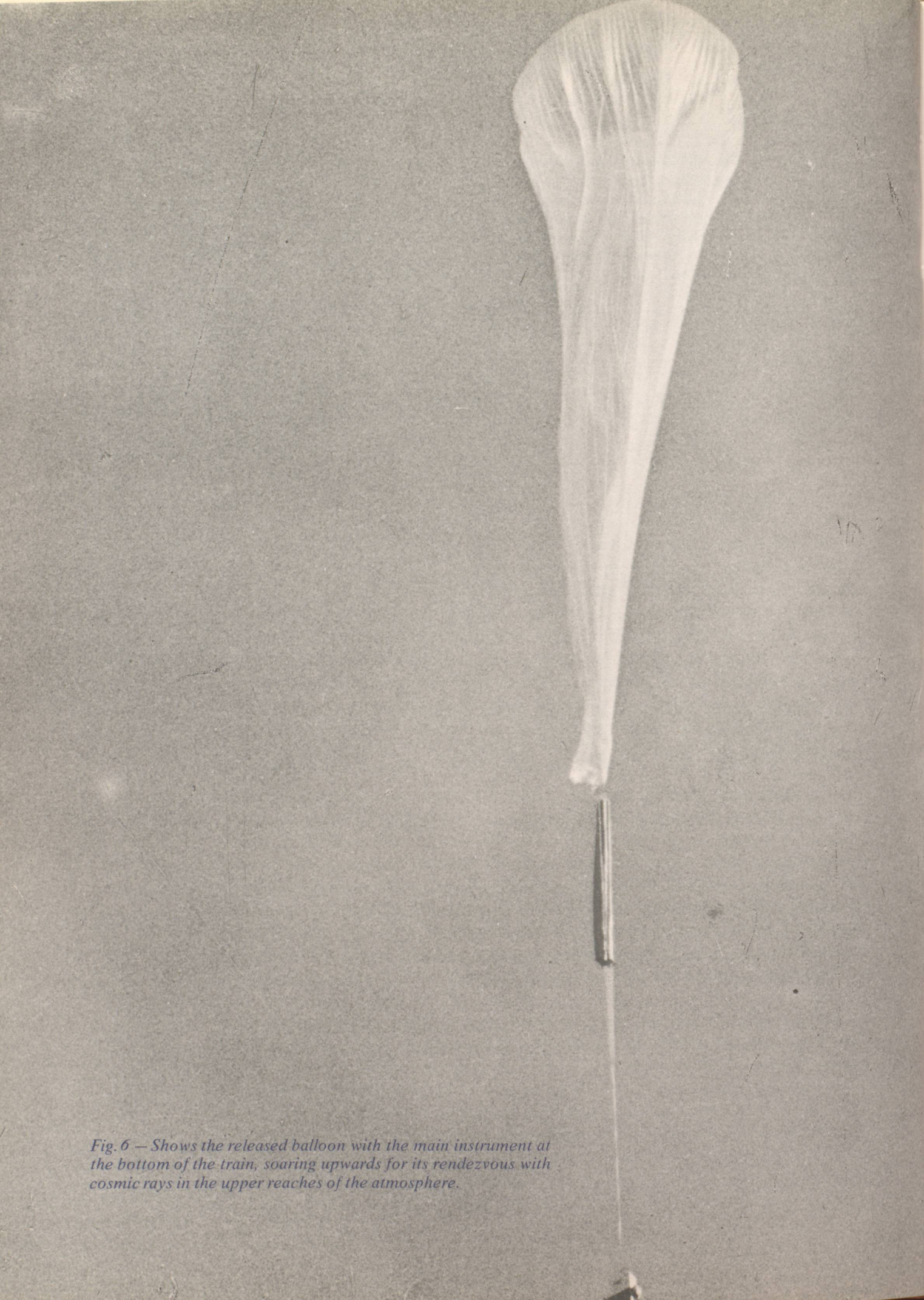


Fig. 6 — Shows the released balloon with the main instrument at the bottom of the train, soaring upwards for its rendezvous with cosmic rays in the upper reaches of the atmosphere.

Experiments on high energy nuclear interactions at energies beyond the range of accelerators were first carried out at the Institute using two cloud chambers at Ooty (altitude 2.2 km and geographic latitude 11° N). Then with time, new detector systems were developed and used: the Total Absorption Scintillation Spectrometer and a large air Cerenkov detector. This work received a further impetus with the commissioning of one of the largest multiplate cloud chambers in the world, of size 2m x 1½m x 1m, and particularly when it was used in association with the major air shower array at Ooty.

Throughout the 1960's, major efforts of the cosmic ray group were directed towards two experimental programmes: on Extensive Air Showers (EAS), and on High Energy Muons and Neutrinos.

The EAS array at Ooty consisted at first of scintillators spread over a large area for determination of shower size, (in the range $10^4 - 10^7$ particles),with appropriate types of nuclear-active particle detectors in the centre; the emphasis was on a study of the detailed properties of individual components of air showers, particularly the fluctuations and correlations of these components. In the next phase, EAS work was extended to a detailed study of high energy interactions in the cores of air showers, by including in the set-up, first the total absorption spectrometer and then the large multiplate cloud chamber. Along with the Ooty experiment, observations on aspects of air showers were made under water and underground at various locations in India including the work at Kolar mentioned earlier.

Over the past decade, there has been series of systematic measurements of muon intensities and angular distributions at various depths in the Kolar Gold Fields up to a great vertical depth of 8400 Mwe (9200 ft. below ground). These were carried out at first with simple telescopes of small area consisting of Geiger counters and scintillators, and later with large area telescopes including visual detector systems for unambiguous observations. A major experiment carried out between 1965-1969, as a joint programme of the Tata Institute of Fundamental Research, Osaka City University, Japan and the University of Durham, U.K., was on the detection and study of interactions produced by natural neutrinos.

The wide variety of experimental cosmic ray research carried out at the Institute, and the important results obtained through these studies, have stimulated theoretical and interpretative work in wide areas of astronomy, astrophysics and cosmology, now termed, cosmic ray astrophysics.

The study of the nucleonic component of the primary cosmic radiation

Work in Major Areas of Current Interest.

Immediately after the discovery of heavy nuclei in primary cosmic rays, it was realised that a detailed knowledge of the relative abundances of the various nuclei and their energy spectra, would be of crucial importance for an understand-

ing of cosmic ray origin and propagation. The first pioneering attempt in this direction by the Institute was made using a stack of nuclear emulsions, consisting of a suitable combination of pellicles of different sensitivities, flown on a balloon in early 1956; this experiment was designed primarily to study the abundance in the cosmic rays of the nuclei Li, Be and B which are exceedingly rare in the universal abundance of elements; it is assumed that if they are present in the cosmic ray beam, this would be due to collisions that have occurred in space, in which heavier nuclei have suffered nuclear distintegrations. Results from this experiment helped in resolving a controversial situation then existing in this subject, in favour of a small proportion of Li, Be and B nuclei compared to the heavier species in the primary radiation. Over the ensuing years many such experiments have been undertaken with emulsion stacks exposed over India, USA and Canada, to cover a wide range of geomagnetic latitudes (and therefore cosmic ray energies) and different periods of time in the 11-year cycle of solar activity. In these experiments the elemental abundances and energy spectra of nuclei ranging from hydrogen to iron have been investigated in great detail; work has also been carried out on the intensity of He^3 isotopes among the doubly charged nuclei. Special mention may be made here of some of the important results obtained: (i) the first reliable evidence was obtained for the very low intensity of nuclei with charges between 15 and 20 compared to lighter and heavier nuclei; (ii) evidence was obtained for the persistence of an even-odd effect of nuclei in the entire range of charges 6-20; (iii) the energy spectrum of the cosmic ray nuclei was determined by the application of a method based on fast knock-on electrons; (iv) the determination of the low energy flux of the different nucleonic components at different times of the solar cycle permitted important conclusions on the solar modulation of cosmic rays and the propagation of cosmic rays in interstellar space.

The great part of the scientific contributions from the Institute on the nucleonic component of the primary radiation during the latter half of the 1950's and the early 1960's were based on investigations using nuclear emulsions flown on balloons from the USA and Canada. During about the same period, considerable amount of pioneering work was carried out in successfully developing a new generation of Cerenkov-scintillator detector system permitting improved studies on the primary radiation. However, unlike nuclear emulsions which can be easily flown on balloons launched from other countries, this instrument had to wait until the 1960's when successful plastic balloon ascents became possible in India. By then a group in the USA had independently developed a similar detector system and had successfully flown it on balloons. However, the important development work then carried out on detector systems and associated electronics and the expertise gained, found timely applications in a variety of cosmic ray experiments including cosmic X-rays and gamma rays from about 1965. In particular, a large magnetic spectrograph consisting of a permanent magnet, nuclear emulsions, spark chambers and other detectors has been successfully developed and flown; in its present form it can cover the momentum interval of 10-150 GeV/c. It is a versatile detector system capable of discovering anti-particles at these energies, if any, in the primary radiation.

The large body of experimental results that have emerged from these researches have enabled a variety of important interpretative deductions to be made concerning the origin and propagation of cosmic rays, as well as concerning the interplanetary conditions that influence cosmic ray particles traversing the solar system.

Cosmic ray electrons

The first successful measurement of the intensity and energy spectrum of primary electrons in the energy interval 10-500 GeV, was made by a group from the Institute using nuclear emulsions flown on a series of balloon ascents from Hyderabad. These studies constitute one of the major and pioneering scientific achievements of the cosmic ray group. It may be of interest to enumerate three

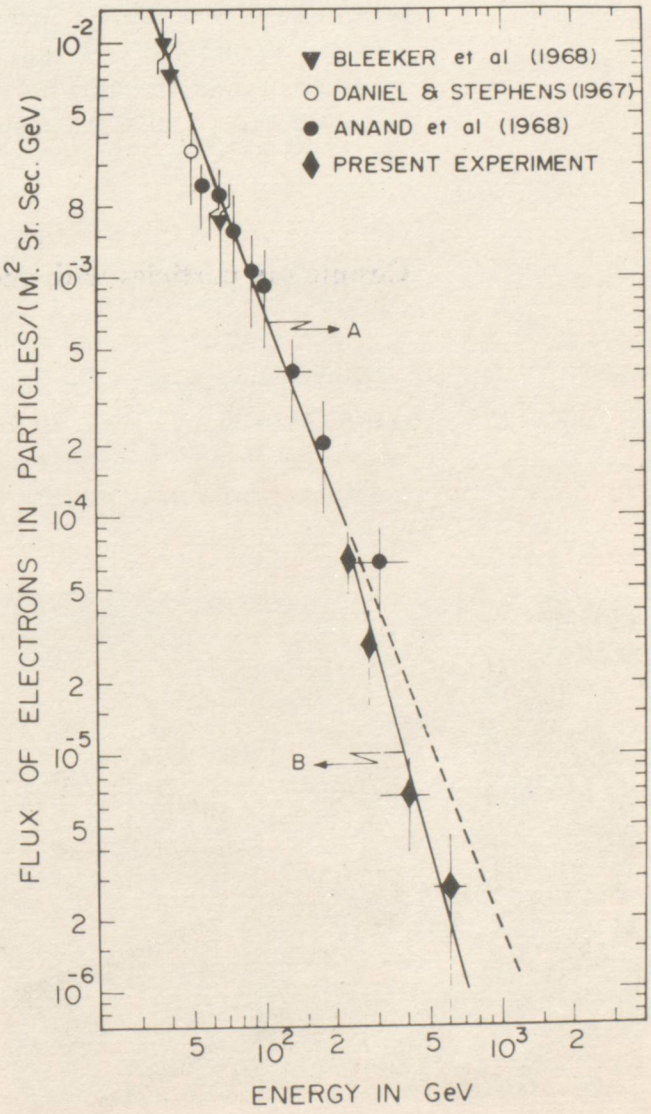


Fig. 7 — The first determination of the primary cosmic ray electron spectrum beyond about 10^{10} eV. These observations have led to very interesting deductions on cosmic ray confinement, the cosmic background radio continuum and other aspects of astrophysical importance.

distinct factors that have been used to advantage in this work: (i) nuclear emulsions constitute the simplest, most unambiguous and reliable detector system for identifying energetic electrons and for determining their energies (at tens to hundreds of GeV); (ii) over Hyderabad the earth's magnetic field permits only electrons of energy greater than about 10 GeV to reach the upper atmosphere and ambiguities due to the presence of low energy particles is avoided; and (iii) for work on the electron component the available balloon flying capability was fully adequate; unusually heavy loads and unusually high altitudes were not needed. The distinguishing feature of electron component, over other components of cosmic rays, is that because of the very low mass, it is vulnerable to energy loss processes in interstellar space through interactions, firstly with weak magnetic fields which give rise to synchrotron radiation, primarily in the radio region, and secondly with radiation fields, due mainly to starlight and the universal microwave radiation at $3^{o}K$, which give rise to hard electromagnetic radiations through inverse Compton scattering. Cosmic electrons can thus be used as a powerful probe to study the state of cosmic space through which they wander during their life; it also demonstrates the intimate connection between cosmic electrons and radio astronomy. Of the results obtained from these studies, special reference may be made to the first reliable 'determination of the energy spectrum of electrons between 10 and 100 GeV and the evidence for the possible steepening of the spectrum beyond; the latter has important implications relating to the propagation of cosmic rays in the Galaxy and related astrophysics .

Cosmic ray particles with energies in excess of 10^{12} eV

Two approaches were adopted to study cosmic ray particles with energies greater than about 10^{12}eV. In the first approach, a large area composite assembly consisting of large areas of emulsion interleaved with tungsten was sent up on balloons; cosmic ray particles of high energy traversing the detector produce

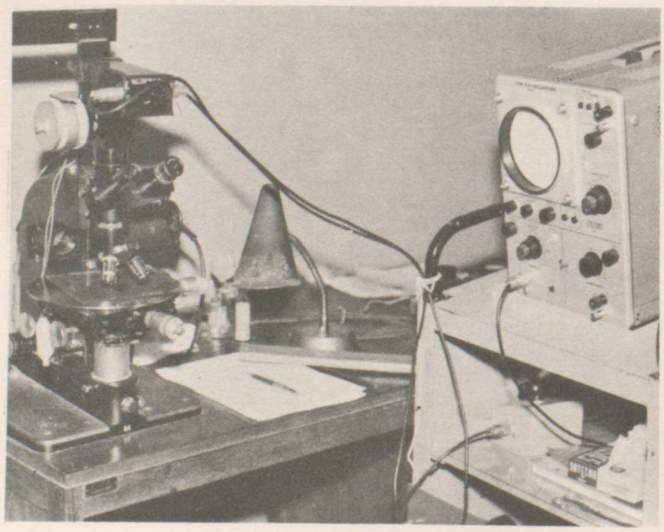


Fig. 8 — Microscope with special attachments to measure by the photometric method the opacity due to tracks produced by heavily ionising particle in nuclear emulsions; similar measurements have been extensively used to measure the energies of ultra high energy electromagnetic cascades.

nuclear interactions which can be detected through the electromagnetic cascades that develop in the tungsten sheets and get recorded in the nuclear emulsion. However, this method becomes increasingly difficult to use in the case of particles of very high energy because of the rapidly decreasing intensity of higher and higher energy particles and the limitations on the area and weight of the balloon borne detector system. In practice this method becomes inapplicable at energies beyond 10^{14}eV.

In the second approach advantage is taken of the extensive air showers (EAS) that are induced by particles of extremely high energy while traversing the earth's atmosphere; the EAS consists of tens of thousands or more particles arriving simultaneously at mountain altitude or at sea level; these events are registered by suitable detecting devices at the observational level spread over a large area. This method has been profitably used in the energy interval of $10^{13} - 10^{16}$eV using an elaborate air shower array set up at Ooty.

The Extensive Air Shower array at Ooty covers an area of about 2500m^2; within this area a large number of plastic scintillators are located. From the response in these detectors the size, the lateral distribution and position of the core of the shower can be computed. In addition, there are four fast scintillators that record the differences in the arrival time of particles in the shower front, from which the direction of the particle inducing the air shower is determined. For measurement of the time differences, a 48-channel nanosecond chronotron timing system is used. The data from all the scintillators is recorded on punched paper tape in a form suitable for analysis straightaway on a fast computer. It is well recognised that particles in the cores of extensive air showers carry information of great importance concerning nuclear interactions at super high energies, and on the mass of particles initiating the showers. In order to obtain

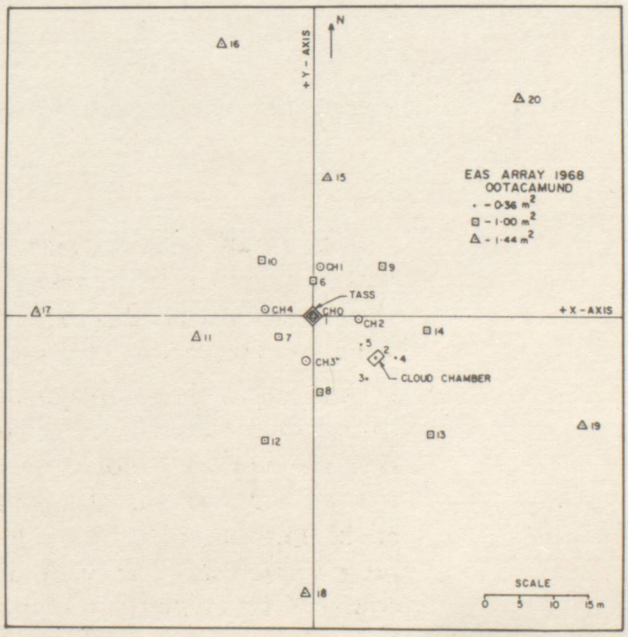


Fig. 9 — Schematic drawing of the layout of the Extensive Air Shower array at the mountain station, Ootacamund (7250 ft. above mean sea level).

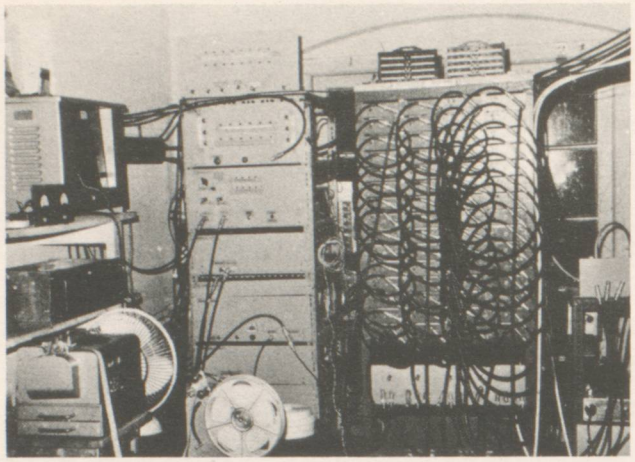


Fig.10—Electronic instrumentation in the recording room of the Extensive Air Shower array at Ooty.

maximum information, a variety of detector systems have been operated at various times in the central part of the EAS array at Ooty. These include a total absorption spectrometer and a large multiplate cloud chamber. From an analysis of the data collected on parameters like the shape of the lateral distribution of electrons, muons and nuclear-active particles, and the variation of the number of nuclear-active particles and low energy muons with size, it has been observed that there are several anomalies in the air shower phenomena in the energy region $10^{14} - 10^{15}$eV. These observations can be best explained on the basis of a model in which the bulk of cosmic ray particles of energy less than about $2\text{-}3 \times 10^{14}$eV are confined to our galaxy by weak interstellar magnetic fields while particles of higher energy leak out. To account for particles seen with energies above 10^{15}eV it is necessary to postulate in this model a second component, probably of extra-galactic origin, which could be a pure proton component. Such a model would also explain the observed behaviour of high energy gamma ray component as a function of depth in the atmosphere.

Cosmic X-rays and Gamma-rays

Soon after the discovery of discrete X-ray sources and the cosmic X-ray background in 1964, it was realised by the cosmic ray group of the Institute that there were special advantages for working in India in this new field of investigation. For the study of hard X-rays with energies in excess of 15 KeV, the location of India near the geomagnetic equator is an advantage in that the unwanted background radiation is kept to a minimum. In addition, the region of the sky near the equator is not conveniently accessible for balloon studies from USA, Europe and Australia. The balloon and high altitude instrumentation capability at the Institute were fully adequate for these studies. Accordingly, a vigorous programme was undertaken in 1967 to study with balloon-borne detectors, hard cosmic X-rays with energies in the range 15-200 KeV arising from discrete sources and diffuse cosmic background. A suitable X-ray telescope mounted on an

oriented platform was successfully flown on five balloon ascents from Hyderabad during 1968-70. These experiments have been very rewarding: the intensity and energy spectrum in the 15-150 KeV band have been measured in the case of a number of discrete X-ray sources, viz. Sco X-1, Cyg X-1, Sgr X-1, Gx-9+9, and also from the diffuse background. The most interesting results relate to: (i) the detection of short period variations in X-ray emission from Sco X-1; (ii) the flat energy spectrum of Sco X-1 in the energy range 50-150 KeV; and (iii) the discovery of at least two new sources of hard X-rays located at high galactic latitudes. The latter discovery of new X-ray sources is of significance, since these sources of hard X-rays are the only ones located at these latitudes. Further studies are in progress.

Immediately after the discovery of pulsars in 1968, X-ray telescopes were flown on two balloon flights from Hyderabad in 1968 and 1969 to search for the emission of pulsed X-rays from four pulsars which can be very conveniently studied at this latitude; from these observations it has been possible to place an upper limit for pulsed X-ray emission from CP 1919.

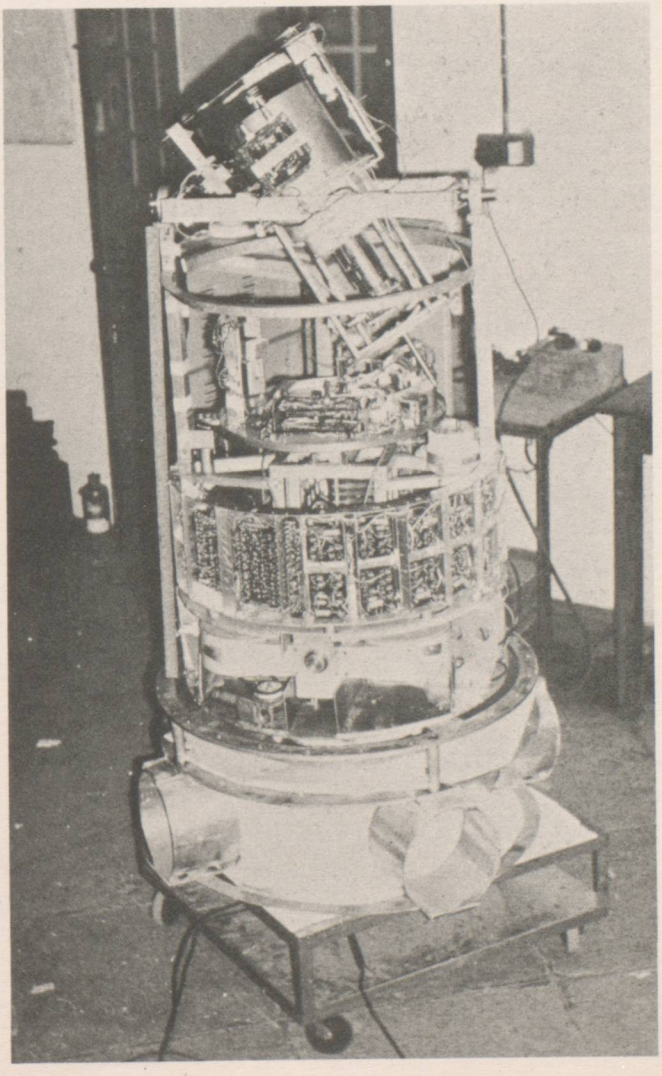


Fig. 11—Detector system for X-ray studies at balloon altitudes. This is mounted on an orienting platform and programmed to look during the flight at selected celestial directions for X-ray sources and diffuse cosmic X-rays. Experiments with such instruments have led to a number of important observations including the discovery of two new X-ray sources.

Preparations for a rocket experiment from Thumba, for studying discrete X-ray sources in the energy range 0.25 — 20 KeV are in progress; a flight with a Centaure rocket is expected in 1971.

In the field of gamma-ray astronomy, studies have recently been initiated using oriented detector systems flown on balloons from Hyderabad. Improved gamma ray telescopes employing electronic detectors and nuclear emulsions are being used to detect gamma rays of diffuse origin, and from the galactic centre and other sources. The detection of cosmic gamma rays by balloon borne detectors is in principle rather difficult because of the low cosmic intensities involved, and the presence of a background of atmospheric gamma-rays; the low atmospheric background over Hyderabad may therefore be of special advantage in the search for cosmic gamma rays.

Another new activity that was started in the summer of 1969 was a systematic search for high energy gamma ray emission, (involving energy greater than 10^{13} eV), from pulsars. The approach is that high energy gamma rays will generate electromagnetic air showers in the atmosphere, and Cerenkov light flashes from these of nanosecond duration can be looked for. A two-mirror automatic electronically controlled star-tracking system was built for this purpose. The first experiment was carried out at Mukurti, near Ooty, in which four pulsars, viz. CP 0950, CP 1133, AP 1541 and P S R 1642, were viewed. Pulsar CP 0950 gave some indications of a positive result. The experimental set-up was moved to Khandala during August-September 1969 because of unfavourable weather conditions in Ooty during these rainy months; further observations on CP 0950 and other pulsars are being continued.

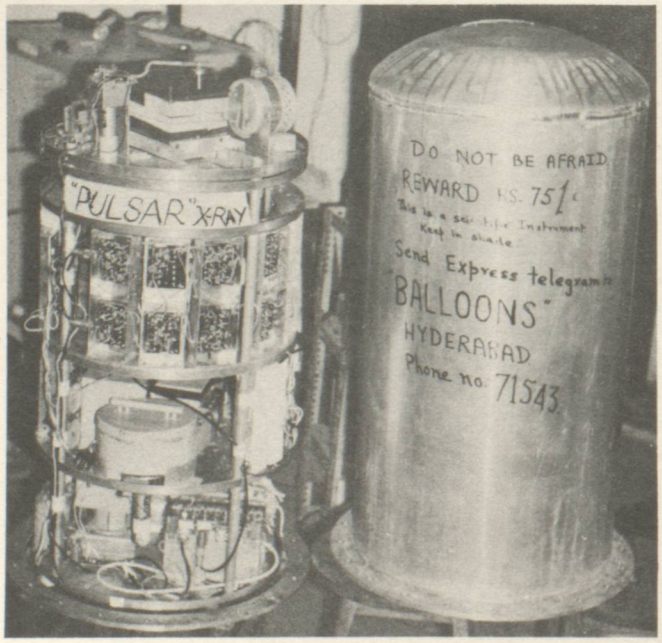


Fig. 12 — An electronic instrument designed to detect possible pulsed emission of X-rays from pulsars; the data is transmitted to the ground receiving station by telemetry. The gondola which will seal the equipment air-tight is shown alongside.

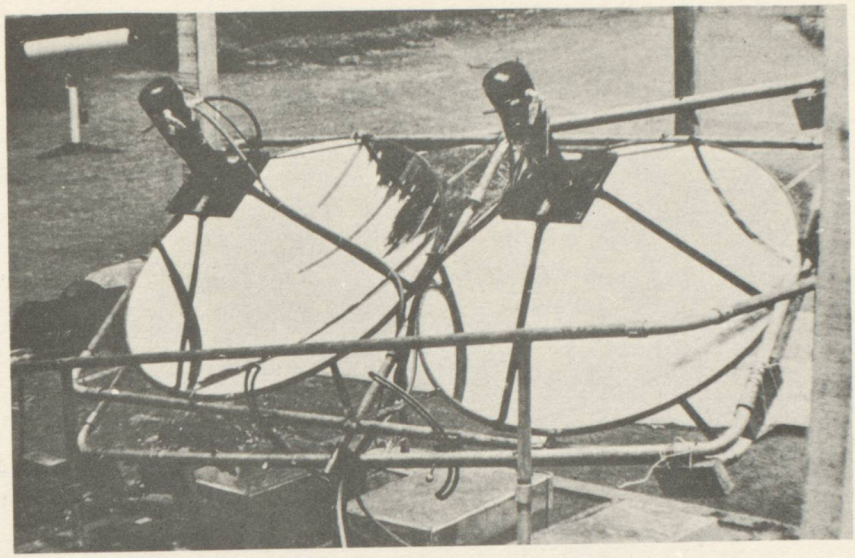


Fig. 13— The reflector system used for automatically tracking pulsars with a view to detect the possible emission from these of gamma rays of energy in excess of about 10^{13} eV. The reflector focuses on a photomultiplier the Cerenkov light emitted by the electron cascade initiated by a high energy gamma ray in the atmosphere.

Solar and Atmospheric Neutrons

It is well-known that when solar flares occur there is often the associated emission of energetic charged particles, X-rays and radio waves—and these components have been detected and studied. One might expect associated emission of neutrons also, but in this case there is the difficulty of detecting such neutrons amongst the large background of low energy protons that is present. Because of the proximity of India to the geomagnetic equator and the consequent reduction in cosmic ray background, it was felt that there would be an advantage in conducting experiments from Hyderabad to detect the emission of such neutrons. Different kinds of detecting systems have been developed and used in this programme. In particular, mention may be made of the use of pulse shape discrimination in a scintillating crystal; this has been successfully developed to separate neutron induced events from gamma ray induced ones. Though no conclusive evidence has yet been obtained on the emission of neutrons from the sun, these investigations have been very encouraging and have also led to other interesting information concerning radiation belts and atmospheric neutrons.

Interpretative and Theoretical Work

Along with the experimental programmes just described there has also been a considerable amount of stimulating interpretative and theoretical work relating to the nucleonic component of the primary cosmic radiation, the origin, acceleration and propagation of cosmic ray nuclei through interstellar and interplanetary space, cosmic ray electrons and related astrophysics, the background microwave radiation and so on.

Results obtained from a study of the relative intensities and spectral shapes of various cosmic ray nuclei at low energies clearly showed that these could not be understood on the basis of the generally accepted notion that all cosmic rays traverse a slab of interstellar path length corresponding to about 3 g. cm^{-2} of hydrogen before reaching the vicinity of the earth; this was clearly a first order simplification. A two component theory of cosmic rays was therefore proposed, in which a second low energy component which had traversed very little matter, was considered to be responsible for the low energy part of the radiation; even this model was found to be not entirely satisfactory. An alternate, and more attractive, model was then worked out, wherein the radiation is assumed to be in a steady state in the Galaxy and the particles instead of going through a constant slab of matter, have an exponential distribution in path lengths; this model explains successfully a variety of observational data which were difficult to understand in the past. Interesting enquiries have also been made concerning the source spectra of cosmic ray nuclei accelerated by a Fermi type mechanism; in this ionisation loss during the acceleration process was incorporated.

Cosmic ray astrophysics related to cosmic ray electrons has been the subject of a series of recent investigations. Observational data concerning cosmic ray electrons and the brightness distribution of nonthermal radio emission from the Galaxy have been combined to deduce the cosmic electron spectrum in interstellar space; and the latter then used to infer information on the origin of these electrons; solar modulation of cosmic ray electrons has also been deduced on this basis. The intensity distribution of the background radio noise received from different

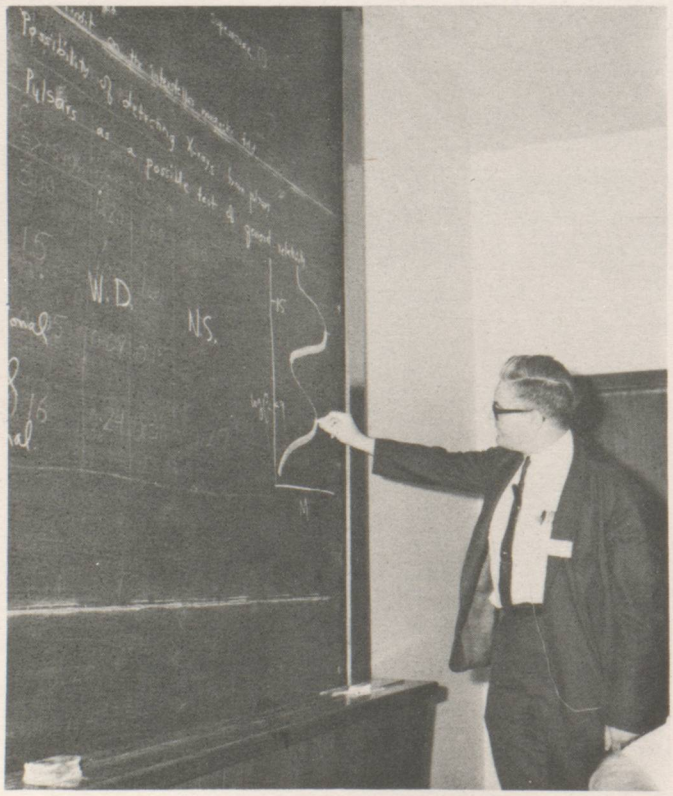


Fig. 14—Prof. A. G. W. Cameron lecturing at the Colloquium on "Cosmic Ray Studies in relation to recent developments in Astronomy and Astrophysics" held at the Institute in November 1968.

galactic directions has been used as a powerful probe to ascribe mean magnetic fields along some favourable galactic directions, and the question of the existence of the radio halo of the Galaxy has been critically examined using the electron spectrum in the Galaxy. From a number of considerations relating to the interstellar electron spectrum, a model in which cosmic rays are primarily confined within the galactic disc, seems to be favoured. A number of consequences arising from the interaction of cosmic electrons with the background photons associated with starlight, the universal 3°K black body radiation and the recently suggested 8°K radiation, all leading to X-rays and gamma-rays, have been the central theme of many investigations. The experimental observations concerning the cosmic background gamma radiation, (in the range of 0.1 to 10 MeV), have several astrophysical and cosmological implications; in view of this the observations have been carefully examined to see whether instrumental responses could be responsible for some of the observed features.

The recent discovery of pulsars, and the new observations on the Crab nebula, have prompted several theoretical investigations aimed towards an understanding of the physical processes in these objects including the production of cosmic rays, X-rays and gamma-rays. A pulsar model has been postulated which has similarities to the solar cycle and solar rotation; if substantiated this would be of considerable importance for our understanding of pulsars in general.

Energetic solar particles and their relation to optical flares have been studied; in particular a model has been proposed in which accelerated charged particles provide energy for the optical flare through the ionisation losses that they suffer in the solar chromosphere and lower corona.

The Balloon facility

Early work using rubber balloons

Balloon flying for cosmic ray research was initiated at the Tata Institute of Fundamental Research in 1948. Prior to this, Homi Bhabha had carried out cosmic ray experiments at airplane altitudes; and he had been deeply interested by the experiments carried out in India by Millikan and collaborators with rubber balloons.

In the early years, 1945-1955, clusters of rubber balloons were employed to carry cosmic ray equipment to altitudes of almost up to 30 km. These flights were conducted from Bombay, Madras, Bangalore, Ahmedabad, Delhi and Srinagar. Investigations using electronic detector systems led to interesting information on the intensity variation with altitude of the penetrating component of the cosmic radiation over low latitudes; and studies with nuclear emulsions, led to exciting results on high energy nuclear interactions, and an elucidation of a variety of properties of the so-called strange particles.

With rubber balloons it was not possible in general to obtain level ceiling performance, nor to carry up heavy loads, and both these aspects were becoming



Fig. 15— During the early days (1945-1955) balloon-borne cosmic ray instruments were housed within cane gondolas. Here Dr. Bhabha is seen participating in a balloon launch from Bangalore in which one of these gondolas was sent up.

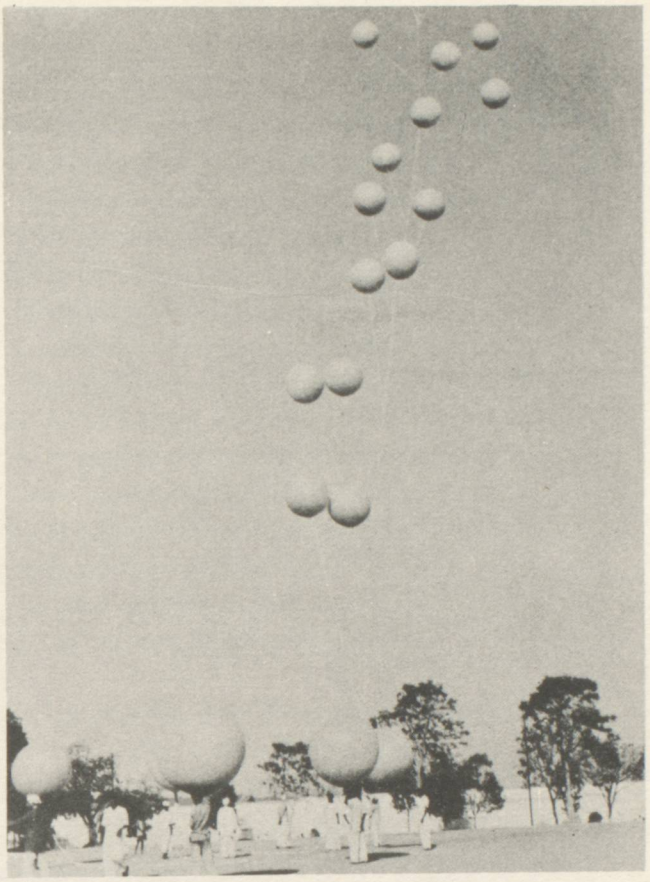


Fig. 16 — Until about the mid-1950, a long train of hydrogen filled rubber balloons was used to provide the necessary lift to carry the cosmic ray instrument to high altitudes in the stratosphere.

increasingly important for most cosmic ray experiments; accordingly, it was decided to develop the technique of flying large, constant volume polyethylene balloons.

Special problems encountered in plastic balloon flights

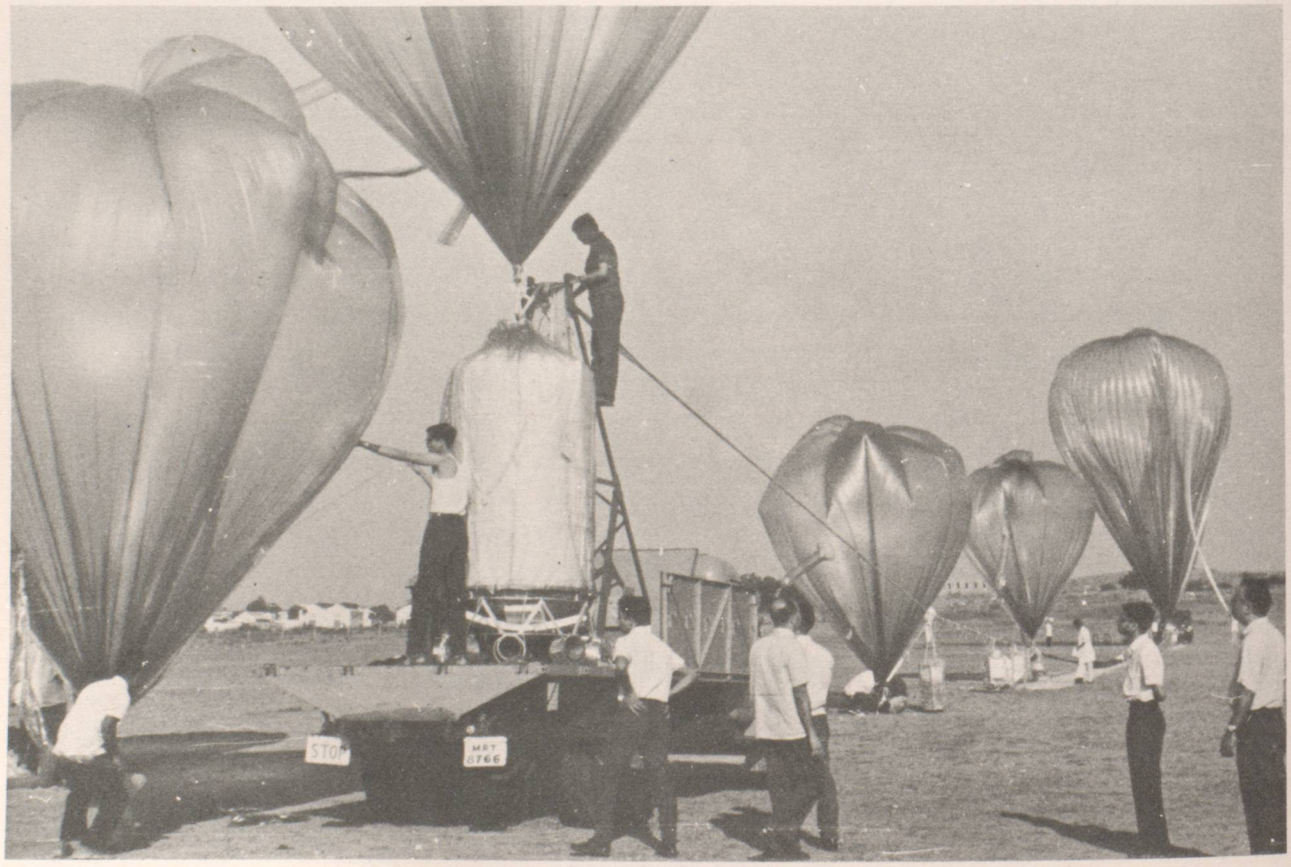
In the USA, where pioneering work had been carried out on the technique of plastic balloon fabrication and flying, the entire chain, starting from the raw polymer and thin plastic film, through balloon design and fabrication to launching and tracking of the balloon, and the recovery of the instruments was a commercial proposition; the experimenter had only to define his requirements within the constraints of feasibility and pay for it. In contrast to this, in India, similar to the situation obtaining in Europe, the concerned cosmic ray group had itself to take on the responsibility for this entire chain.

The first serious problem encountered here related to the cold brittle properties of the film used for balloon fabrication. Most polymers used for the extrusion of ordinary thin polyethylene film have a cold brittle point between -50°C and -60°C. With specially chosen polymers and controlled extrusion, the cold brittle point could be lowered to -72°C; and this was achieved, and film with these properties was available to balloon flight groups in the USA in the 1950s. ('Stratofilm' recently developed in the USA by Winzen Research Inc. has a brittle temperature of -84°C). However, film with cold brittle points between -50°C

and -60°C was the only one available in India through local production or through import. But on the other hand the temperature of the tropopause over low geographic latitudes, as in India, is as low as -80°C and less, compared to that over high latitudes (in USA and Europe) which is about -65°C.

All early ascents carried out by the Institute with balloons made of thin transparent polyethylene film were found to fail at altitudes between 40-60,000 ft. The failures were characteristic: the balloons shattered like a glass thrown on the floor. It was clear that the balloon fabric had become brittle at these altitudes. It is amusing to look back on some of the early attempts to solve this problem, including the painting by hand, (in black and reddish-brown) of several balloons — and these survived ascent through the tropopause! Paint does not easily adhere to polyethylene film and painting was both messy and uncertain. A more permanent solution was easily found by incorporating in the film, at the time of extrusion, a small amount of carbon black to enable the film to absorb sufficient solar radiation to prevent cold fracture; too high an absorptivity resulted in high rates of ascent and poor performance at ceiling. Uniformity in absorptivity was important to ensure that local scorching due to too large an absorptivity at places did not occur.

Fig. 17 — All set for the launching of a 4 million cubic feet balloon to carry a magnet spectrograph to study the possible existence of antinuclei in the primary cosmic radiation. The instrument weighed about 400 kg; the gross load of 1100 kg. was the heaviest successfully launched so far.



During the early days of plastic balloon development, considerable assistance was obtained from the group under Prof. C. F. Powell at the University of Bristol in England. The launching platform used here was very similar to the one employed by the Bristol group; this platform was designed to hold the small upper part of the balloon in which the hydrogen gas was filled, and then to measure the exact lifting power acquired by this bubble of gas. At launch, the clamp holding the balloon was suddenly released and the balloon would ascend with considerable acceleration; this was due to the fact that the bubble did not have on it, at that stage, the full load due to the main part of the balloon and the load line below; the lifting power at launch was therefore considerable. In this acceleration, as a result of air resistance, the top of the balloon would be flattened out (called "mushrooming") and often gave way under the stresses encountered. This problem was overcome by appropriate design and reinforcement of the top part of the balloon; and later by employing the truck method of dynamic launch in which the gas bubble, which was given the lifting power, had always the full load pulling on it through a taut line; the situation at launch with this technique is similar to that in flight.

With the introduction of coloured film to avoid brittle fracture in the upper regions of the troposphere, and with a design capable of withstanding the stresses encountered at launch, the balloon programme was well on its way to success. Rapidly, technical inprovements were carried out to make possible the fabrication of larger balloons, both to attain higher ceilings and to carry heavier loads; load tapes were used for the latter purpose. Many variations of heat seals were tried including the hot roller seal and the hot wire seal, before the more reliable and semi-automatic band sealing technique was adopted.

It might be pointed out that there are many differences between coloured balloons and transparent balloons in aspects relating to heat transfer, (between the fabric and the hydrogen inside and air outside), and the temperature of the hydrogen at the various stages of ascent. Coloured balloons ascend much faster than transparent balloons. Therefore, in the case of coloured balloons, they are given a lifting power which is smaller than the gross load i.e. weight of the balloon plus everything on the load line; the additional lifting power needed for the launch is given to smaller launch balloons attached to the load line; these lose gas rapidly during ascent by which time the main balloon has heated up and taken over. It is important to exude the excess gas in the right quantity and at the right rate as ceiling is reached, to obtain level performance at the ceiling altitude theoretically expected; the balloon design has to take care of this.

Special advantages

For a decade since 1959, plastic balloons have been launched regularly from the campus of the Osmania University in Hyderabad; the geographic location of Hyderabad is 17.6° N and 78.5° E; the geomagnetic latitude is 7° N and the corresponding geomagnetic cut-off rigidity for cosmic ray particles arriving vertically over Hyderabad is 16.9 GV. After extended exploratory work, Hyderabad was

selected as the launch site for a variety of reasons: the low geomagnetic latitude; its location in the middle of the subcontinent which allows for a sufficient land mass over which the balloons can drift east or west, and the payload can then be recovered over land after a reasonable duration at the float altitude; the terrain east and west, except for limited regions, is easily accessible by jeep and is generally well populated, thus facilitating recovery operations.

Osmania University, Hyderabad, has provided to the balloon team from the Institute all possible support, including the use of the ground for launch operations, hostel and laboratory facilities and workshop assistance; and the Institute would like to place on record here its deep gratitutde to the Osmania University for this, without which the balloon flight programme would not have achieved the success it did. Since 1970, for reasons which are described a little later, the entire balloon operations have been shifted to a new site bordering the Electronics Corporation of India (ECIL) at Maula Ali, Hyderabad.

National and International programme

Being close to the geomagnetic equator, the balloon flying facility at Hyderabad is favourably located for many investigations on cosmic rays and atmospheric research. The high cut-off rigidity permits the study of the high energy cosmic ray particles without the background of the large flux of low energy particles; also, the reduced overall intensity of cosmic rays makes it ideal for studying neutral cosmic radiations such as X-rays, gamma-rays and solar neutrons. The balloon facility has been made freely available to all institutions in India which can make use of it. The Physical Research Laboratory, Ahmedabad makes regular use of the facility for cosmic ray research. Additionally, the India Meteorological Department, the Thumba Equatorial Rocket Launching Station and the Osmania University have made occasional use of the facility.

Over the last decade many Universities and research institutions from abroad have conducted research programmes from Hyderabad. In 1961, a joint Indo-US expedition was carried out under the auspices of the Department of Atomic Energy. In this series, the American flights were carried out by a balloon crew from General Mills Inc. (Minneapolis) on behalf of the Geophysics Research Directorate of the Air Force Cambridge Research Laboratories. The American flights carried instruments for geophysical research such as sub-micron aerosol collectors and small and large impactors; on the Indian flights nuclear emulsions and electronic units were sent up for cosmic ray research. A total of about 20 balloon ascents were made, including the successful exposure for 30 hrs. at 85,000 ft. of a ⅔ ton emulsion-tungsten assembly for a joint research programme of the University of Bristol and TIFR on nuclear interactions at very high energies.

In 1965, an international flight expedition was jointly organised by the Institute and the National Centre for Atmospheric Research Boulder, Colorado, USA (under the auspices of the National Academy of Sciences-National Science Foundation, USA) to study cosmic rays in the vicinity of the equator during the International Quiet Sun Year (IQSY). A total of 17 flights were then carried out

for institutions all over the world; these included the New York University, the Air Force Cambridge Research Laboratories, the University of California at Berkeley, the University of Minnesota, the Naval Research Laboratory, Washington, the University of Rochester, the South West Centre for Advanced Studies, Dallas, all from USA, the University of Bristol, U.K., the Dublin Institute for Advanced Studies, Ireland, the University of Tasmania, Australia, the Osmania University, Hyderabad and the Tata Institute of Fundamental Research. The heaviest payload launched in this series weighed 2858 lbs.

Further to these two expeditions, other collaborative balloon programmes have also been carried out. As a part of a collaboration between the Smithsonian Astrophysical Observatory, Cambridge, USA and the TIFR, a continuing series of balloon flights have been made from Hyderabad over the period 1967-1971 for the study of cosmic gamma rays. Again, a continuing series of balloon experiments has been in progress since 1968 between TIFR on the one hand and the University of Nagoya and the University of Tokyo, Japan, on the other, for studies on cosmic X-rays and X-ray sources. In 1970, a collaborative programme was conducted jointly by the University of New Hampshire, Durham, USA and TIFR, for the study of cosmic gamma rays.

Existing facilities and capabilities

Polyethylene films

Polyethylene film required for the fabrication of balloons is extruded in a factory in Bombay according to desired specifications under the supervision of scientists from the Institute; the polymer used is an Indian polymer, DFDI-6600 manufactured by Union Carbide (India). Round-the-clock quality control is maintained during the time of extrusion by Institute personnel. Aspects checked carefully are: uniformity of thickness and of absorptivity, absence of pinholes and tensile strength in different directions. Films with thicknesses between 1.1 and 1.5 mil. and an absorptivity of 10-12% are extruded. Balloons made out of such film have given completely satisfactory performance for flights during day time.



Fig. 18 — Balloon production. Constant volume balloons, of volume upto 3 million cubic feet, are manufactured in the Institute using polyethylene film extruded in a Bombay factory using an Indian polymer.

Fabrication of balloons

Until April 1970, the balloons were made at the Institute in Bombay on a special table about 300 ft. in length. For sealing the gores together, radiant heat from a long hot wire was used; this technique had been developed at the Institute and successfully used for making small balloons. The hot wire technique results in a bead-seal, which has limited extensibility at low temperatures and would thus result in seal breaks. In order to avoid in the case of very large balloons, occasional failures which may be caused by this, and to improve further the ceiling performance of the balloons by eliminating any possibility of gas leaks, successful tests, were made with a band sealing technique. This sealing process is easily machanised and the production of large balloons takes only about 10 days, which is about half the time taken by the previous method. With effect from October 1970, balloons have been produced using this sealing technique in a newly constructed building adjacent to the launching site at Hyderabad.

Balloons of volume upto 3 million cubic feet (mcft) have been successfully made and launched; these balloons have a length of over 250′ and a diameter of about 150 . Ceiling altitudes upto about 1,20,000 ft. have been attained and constant ceiling altitudes maintained upto 8 hours.

Launching, tracking and recovery operations

The launching of large volume plastic balloons requires special gear, and calls for expert operations by the crew; they are often required to take split second decisions at times of emergency. Over a period of years such a crew has been selected and trained.

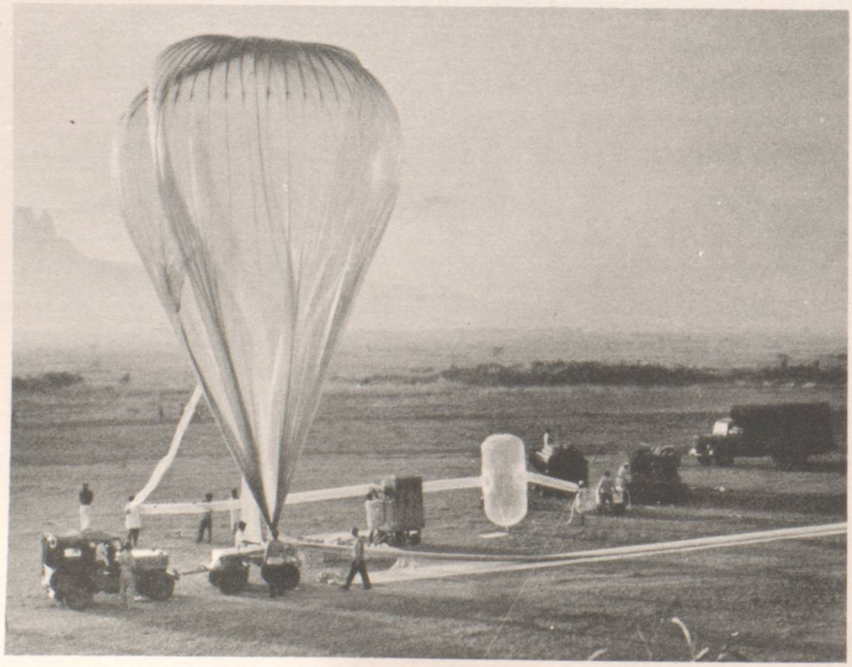


Fig. 19 — Hydrogen filling operations. Hydrogen from a bank of high pressure cylinders, after passing through a heat exchanger, a buffer balloon (to minimize sudden changes of pressure) and a gas meter, is fed into the top bubble through long filling tubes.

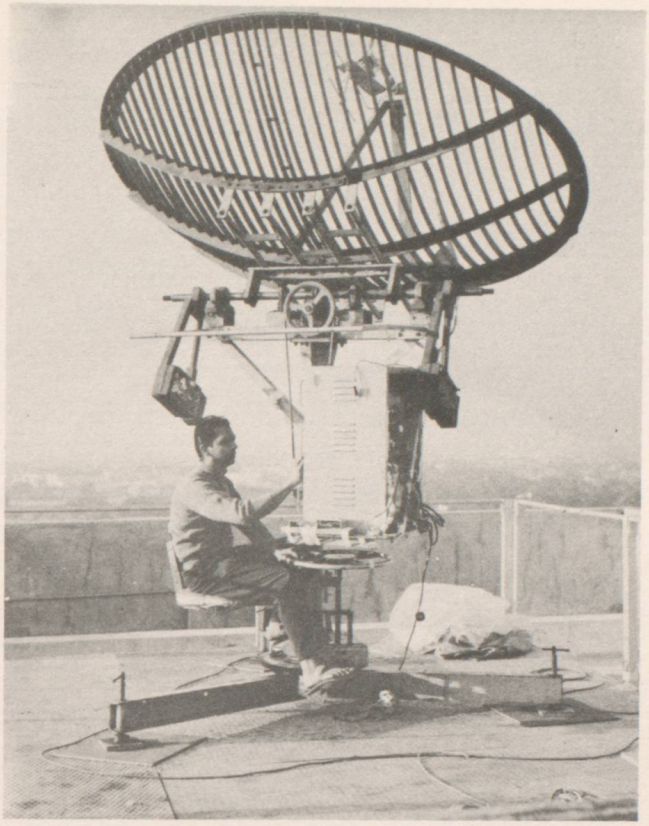


Fig. 20 — After launch the balloon is tracked by a steerable radio direction finder; this picture shows one fabricated at the Institute.

Tracking is carried out by three independent methods: (a) radio tracking, using a mechanical steerable direction finding antenna designed and fabricated at TIFR, with a range of about 500 km; (b) optical tracking using theodolites stationed at 2 or 3 widely separated locations, which provide a range of about 200 km. on a clear day; and (c) radar tracking made with the cooperation of the India Meteorological Department, using the Selena radar stationed at Hyderabad, which has a range of about 200 km.

The instrumental load is brought down at a pre-determined time by a timer-device which triggers a squib. When the flight has to be aborted or terminated earlier, this can be done with a radio command from the ground; the range of this is about 500 km. The instrument descends to the ground on a parachute and is recovered by a party soon after the impact. The recovery rate has been near 100%. Over the last nine years about 100 balloons with volumes in excess of 1 mcft have been launched from Hyderabad; the largest of these are the 3 mcft ones; payloads upto 500 kg. in weight have been flown.

Flying season

Balloon flying has been carried out thus far between February and April of each year, primarily because of excellent meteorological conditions, both in terms of weather conditions at ground level for launch, and suitable winds at high

altitude which permit flights of long duration and are such that recovery of payload is fairly certain. With the commissioning of the new balloon base at Maula Ali, flights can, in principle, be performed at any time of the year. Ground conditions for launch are unfavourable between May and August owing to summer and monsoon conditions. Between October to January, flight durations at ceiling altitude are likely to be limited since the upper winds are expected to be westerly and high; if this is so, the payloads will normally be carried to inaccessible terrain; our information concerning this is rather scanty at present. Wind soundings are being carried out on a regular round-the-year basis to obtain reliable information on upper winds.

So far balloons made at the Institute have been launched only during day time since the fabric needs solar radiation to avoid brittle fracture in the upper troposphere. There are, however, many experiments, as in X-ray and gamma-ray astronomy, where night launches are required. To satisfy these demands night flights are being carried out with balloons made here from "stratofilm" developed by Winzen Research Inc.; the brittle temperature of stratofilm is low enough to withstand the temperatures in the upper troposphere over Hyderabad.

The New Balloon Base

The new balloon base at Hyderabad consists of: (i) a two-storeyed hostel with 18 double rooms to house all those engaged in balloon operations and experiments; (ii) a cafetaria; and (iii) a two-storey laboratory–workshop building with an observation tower overlooking the launch ground. Adjacent to these buildings are located a 400 ft. long building for balloon production, and sheds for vehicles and hydrogen gas storage. The launch ground, at present, is about 1500 ft. x 1500 ft. and has hard packed grass turf that is quite suitable for the manouevring of large trucks. There is provision for illuminating the ground for night launches.

In the laboratory cum workshop building there are four airconditioned laboratories, a photographic dark room and a projection room; these are used



Fig. 21— The laboratory building with the observation tower overlooking the launch ground at the Balloon Facility at Maula Ali, Hyderabad.

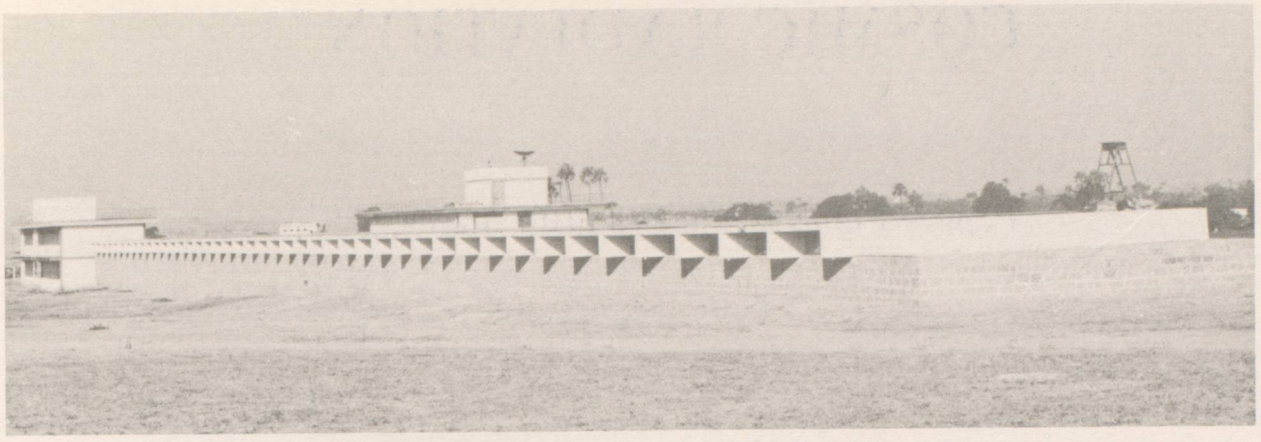


Fig. 22— The new 400 ft. long balloon production building at the Balloon Facility, Hyderabad. Balloon production was shifted from Bombay to Hyderabad in September 1970.

mainly for preflight preparation of scientific payloads. A small machine shop and the balloon rigging area are located on the ground floor. At the end of the building is a roll-up type door that is large enough for the launch truck to pass through so that the prepared scientific payload can be loaded directly on the launch platform. Offices, and a room for maintenance and calibration of the balloon support equipment, are located on the second floor. The observation tower at the next level is also used as the control room during flights; this room is airconditioned.

Concluding Remarks

Balloon flight programmes conducted all over the world have had more than their share of fun and excitement. Stories concerning men, incidents and accidents connected with the TIFR programme will match those from anywhere else. But with the fun there has also been success. The high altitude cosmic ray programmes of the Institute have achieved what they have on the strength of the indigeneous balloon capability that has been built up. And the efforts and the story will go on: larger balloons, higher altitudes, longer flights, heavier payloads.....

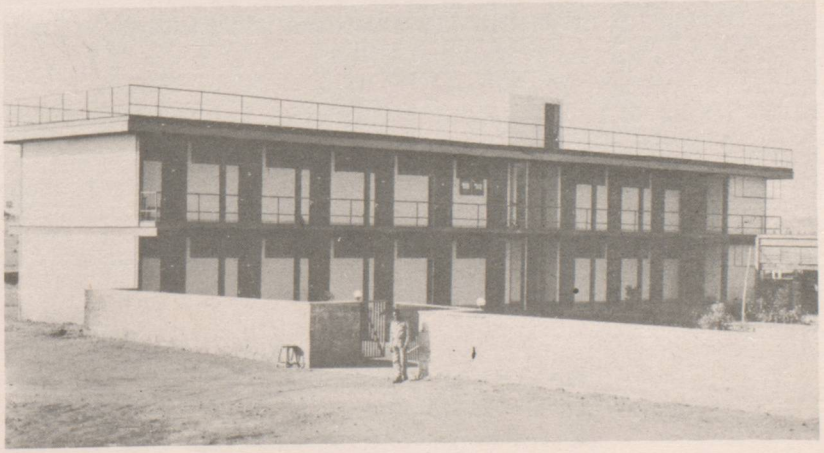


Fig. 23— Adjacent to the laboratory building at the Balloon Facility at Hyderabad there is an 18-room hostel in which scientists and technicians engaged on balloon operations can stay.

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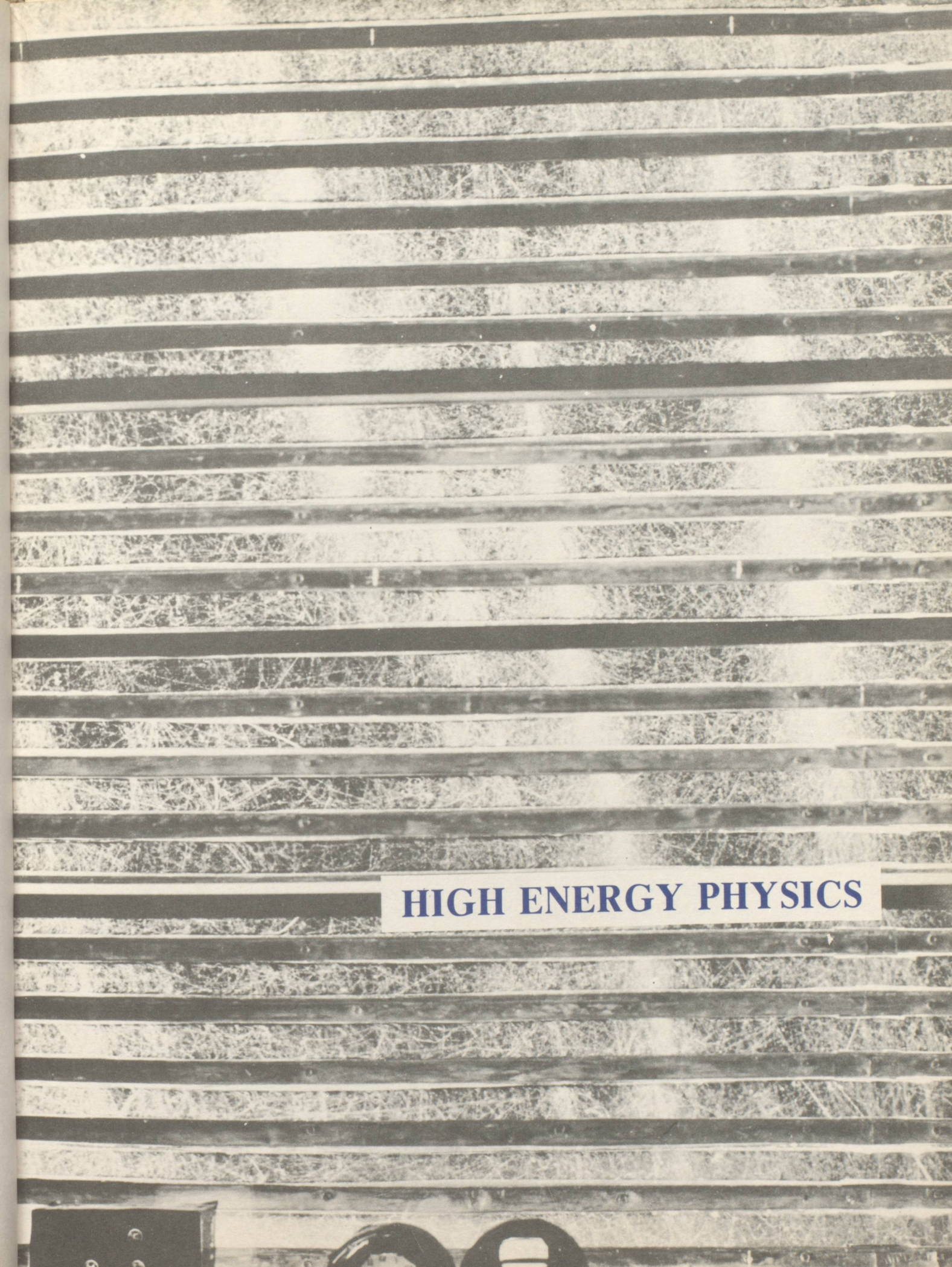
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HIGH ENERGY PHYSICS

HIGH ENERGY PHYSICS

Situation prior to 1947

Historical Background

When the Institute was founded in 1945, the family of elementary particles consisted of just seven particles, namely, photon, electron positron, proton, neutron and muon (negative and positive) and neutrino (hypothetical). Of these, the positron and the muon were discovered in 1932 and 1937 respectively, as a result of cosmic ray studies.

Another important observation of cosmic-ray phenomena made earlier was that of the existence of the so-called soft showers. The soft showers, which consist of the cascade development of electrons and photons in material media, were understood in terms of the quantum theory of electrons and photons to which Dr. H. J. Bhabha, the Founder Director of the Institute had contributed a great deal in 1935 and later.

The discovery of the muon had generated considerable interest in its properties as it was thought that this could be the particle predicted by Yukawa in 1935 to be responsible for nuclear forces. A detailed study of the properties of the muon, however, belied these hopes and therefore the hunt for the Yukawa particle was still on.

At the time the Institute was founded it was well known that a study of cosmic radiation could provide a means of starting experimental research work in the field of elementary particles. Further impetus to the study of cosmic radiation came later from the discovery of the pion at Bristol by Powell and collaborators in 1947 and its eventual identification as the Yukawa particle.

The techniques of investigation of elementary particle phenomena in cosmic radiation at that time were mainly that of the Wilson cloud chamber and the Geiger-Mueller counters. Nuclear emulsion was just then being perfected by Powell and collaborators at Bristol for the study of cosmic ray phenomena. One must also mention here the balloon flight technique without which nuclear emulsion technique could not have made as great an impact as it has done in the fields of cosmic rays, elementary particles and high energy physics. Thus the early efforts in the Institute consisted of developing and using these techniques for the study of various elementary particle phenomena in cosmic rays.

A multiple-core event recorded in the cloud chamber operated in conjunction with an extensive air shower array of detectors at Ootacamund. It is possible to estimate the energy of each of the cascades in such an event as well as their mutual separation. The background of tracks seen in this photograph corresponds to the extensive air shower (electrons, muons, hadrons).

Later Developments

The discovery of the pion in 1947 is one of the most important landmarks in elementary particles. This was soon followed by the discovery of multiple meson production which was the beginning of a great interest in the study of high energy phenomena. Right around that time, while carrying out a cloud chamber investigation, Rochester and Butler in England obtained photographs of two events in which tracks had the configurations of V. These were later shown to be due to two new particles, now called the kaon (K) and the lamda(Λ). This was the first indication that the discovery of pion was not an isolated phenomenon and that one might reasonably well expect a whole family of strongly interacting particles. These expectations were proved to be justified by the large number of so called elementary particles which were discovered in the later years.

By the mid fifties proton accelerators, the 2 GeV Cosmotron at Brookhaven and the 6 GeV Bevatron at Berkeley produced artificially the K-mesons and hyperons and thus, as in the case of pions, detailed study of these particles was undertaken with these accelerators. The cosmic ray intensity was far too low compared to that required for a detailed study of these new particles. The construction of the 6 GeV Bevatron also resulted in the discovery of the antiproton. It was around this time in 1956 that the well accepted principle of parity conservation in weak interactions was overthrown as a culmination of the well-known τ-θ puzzle. The construction of a 10 GeV machine at Dubna in 1957, a 25 GeV proton synchrotron at CERN in 1959 and a 30 GeV proton synchrotron at Brookhaven resulted in a great spurt of activity in elementary particles and high energy physics. Thus, Σ° Ξ° Ξ^- Ω^- ν_μ ν_e and a galaxy of the so called resonances, whose decays are characterised by strong interactions, were discovered. Once again another important conservation law fell through. This time it was CP conservation, which has been recently shown to be violated in K°-decay, although the magnitude of violation is indeed small.

One of the striking early observations made with the development of nuclear emulsion sensitive to minimum ionising particles was that of multiple meson production. It was observed that when a high energy cosmic ray particle collided with, say, one of the emulsion nuclei, it invariably resulted in a large number of secondary particles. This phenomenon of multiple meson production received considerable attention in the years to come and is still being pursued with considerable interest. A variety of detectors such as, counters, nuclear emulsion, cloud chamber, total absorption spectrometer, etc. have been used. Inspite of the fact that the energy of the primary particle is generally difficult to determine to any high degree of accuracy in cosmic ray experiments, a number of broad features of nucleon-nucleon collisions at high energy have been established. In this area of research, the cosmic rays have always played a leading role and although the cosmic-ray experiments are arduous because of the small available flux and lack of knowledge of precise primary energy, it appears that for quite some time to come this would be the only means of getting information on nuclear processes at energies beyond about 500 GeV.

The last statement must be qualified with one exception and that is the Intersecting Storage Ring, at CERN, which is scheduled for commissioning during the middle of 1971, is expected to provide some valuable information on nucleon-nucleon collisions at an equivalent laboratory energy of up to about 1500 GeV.

Research Activities and Achievements

The very early experiments in particle physics undertaken by the Institute consisted of investigating the properties of muons with G.M. counters and Wilson Cloud Chambers filled with metallic plates (in the absence of a magnetic field) at sea level and underground, and the study of nuclear interactions of cosmic ray particles using nuclear emulsion at various altitudes in the atmosphere. The counters and nuclear emulsions were flown to high altitudes, 60,000 ft. and upwards, for the study of cosmic rays. For this purpose, the technique of flying rubber balloons was on hand since it had been developed by Bhabha from as early as 1943. At the time of the international conference on Elementary Particles held at the Institute in 1950, these techniques of study were well in use in the Institute. A significant result reported at the conference came from an investigation carried out at the Institute. This concerned with an hitherto unobserved maximum in the intensity of the penetrating component of cosmic radiation (mostly muons) at 120 millibar level. This result was consistently interpretable in terms of mesons being secondary particles produced in the nuclear interactions of primary protons in the upper layers of the atmosphere.

In the early years of the fifties, vigorous investigations on the properties of nuclear interactions of primary cosmic ray protons and the phenomenon of multiple meson production in photographic emulsions were initiated under the direction of Prof. B. Peters. Nuclear emulsions were exposed at various altitudes in balloons and recovered for processing and study. The technique of following tracks of charged particles in stripped emulsion through several layers (without the usual glass backing) was developed and this yielded new results on the properties of heavy unstable particles designated later as K-mesons and hyperons. Several decay modes of the K-mesons were identified in the nuclear emulsion block detectors, such as the τ and θ decay modes. A new discovery made at the Institute was the existence of negative K-meson which did not decay on coming to rest in the emulsion like the positive one but was captured by nuclei of the photographic emulsion which disintegrated through transformation of the rest-mass-energy of the K-meson. By these discoveries and similar others in cosmic radiation throughout the world, evidence for the existence of a large number of 'elementary' particles produced in nuclear interactions of cosmic ray particles was established.

In parallel with carrying out studies of elementary particles and nuclear interactions at high energies using the cosmic rays, the Institute has also made important contributions from investigations involving accelerators. The Institute has carried out a number of investigations to study characteristics of nuclear collisions of particles using nuclear emulsions exposed to various beams from different accelerators, such as 6 GeV Bevatron at Berkeley, 24 GeV CERN Proton Synchrotron at Geneva, 10 GeV Synchrotron at Dubna, etc. The first

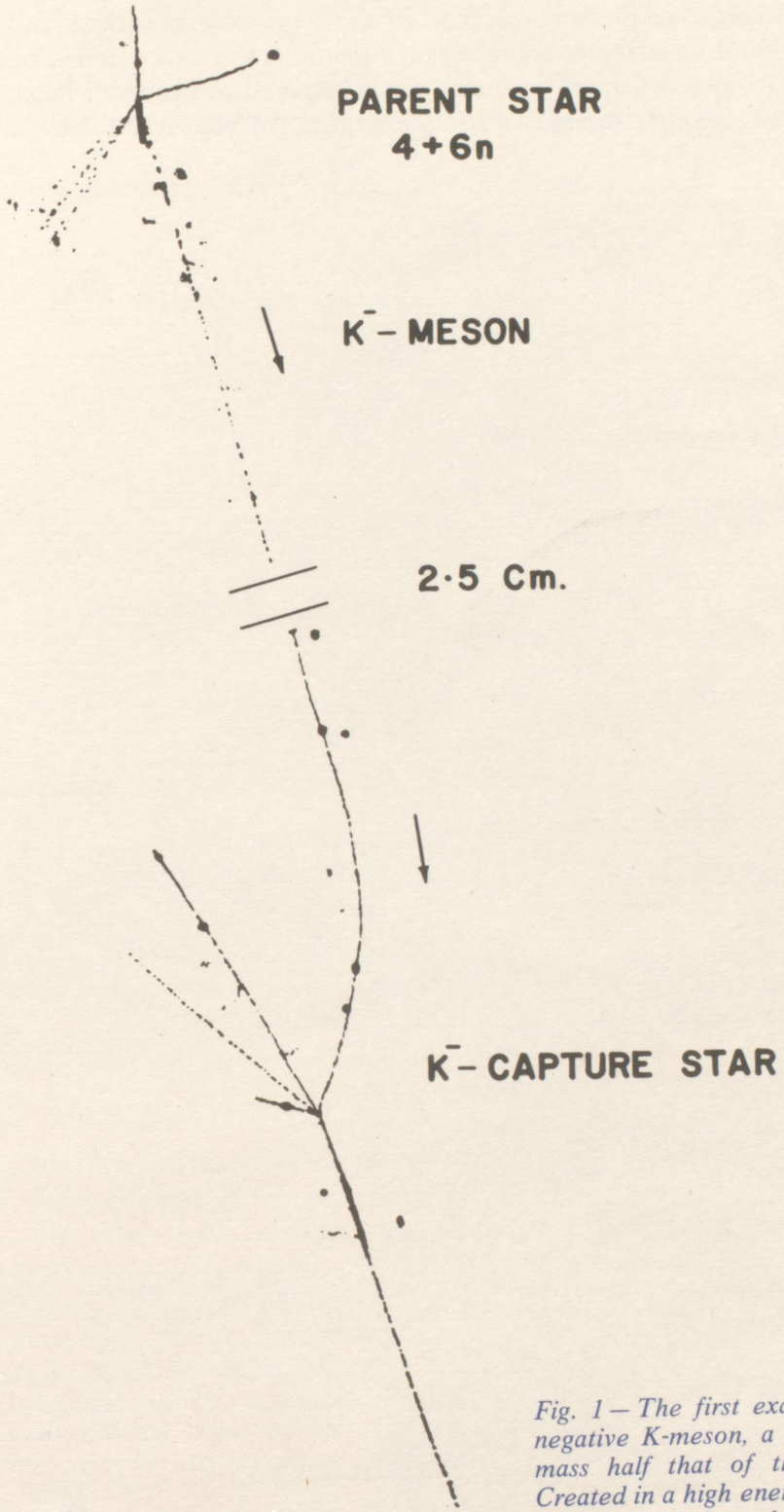


Fig. 1 — The first example of a negative K-meson, a particle of mass half that of the proton. Created in a high energy nuclear collision, it is brought to rest in the photographic nuclear emulsion where it is captured by a nucleus causing it to disintegrate.

such investigation concerned with a detailed study of proton nucleon collisions at 6.2 GeV using nuclear emulsions exposed to the Bevatron at Berkeley. This was followed by a number of investigations carried out to study interactions of 17 GeV/c negative pions in carbon, 24 GeV protons in carbon and 4.3 GeV negative pions. A series of important investigations were also carried out to study hypernuclei in a variety of emulsion stacks exposed to beams of negative pions, protons and negative kaons of various energies. An important observation made

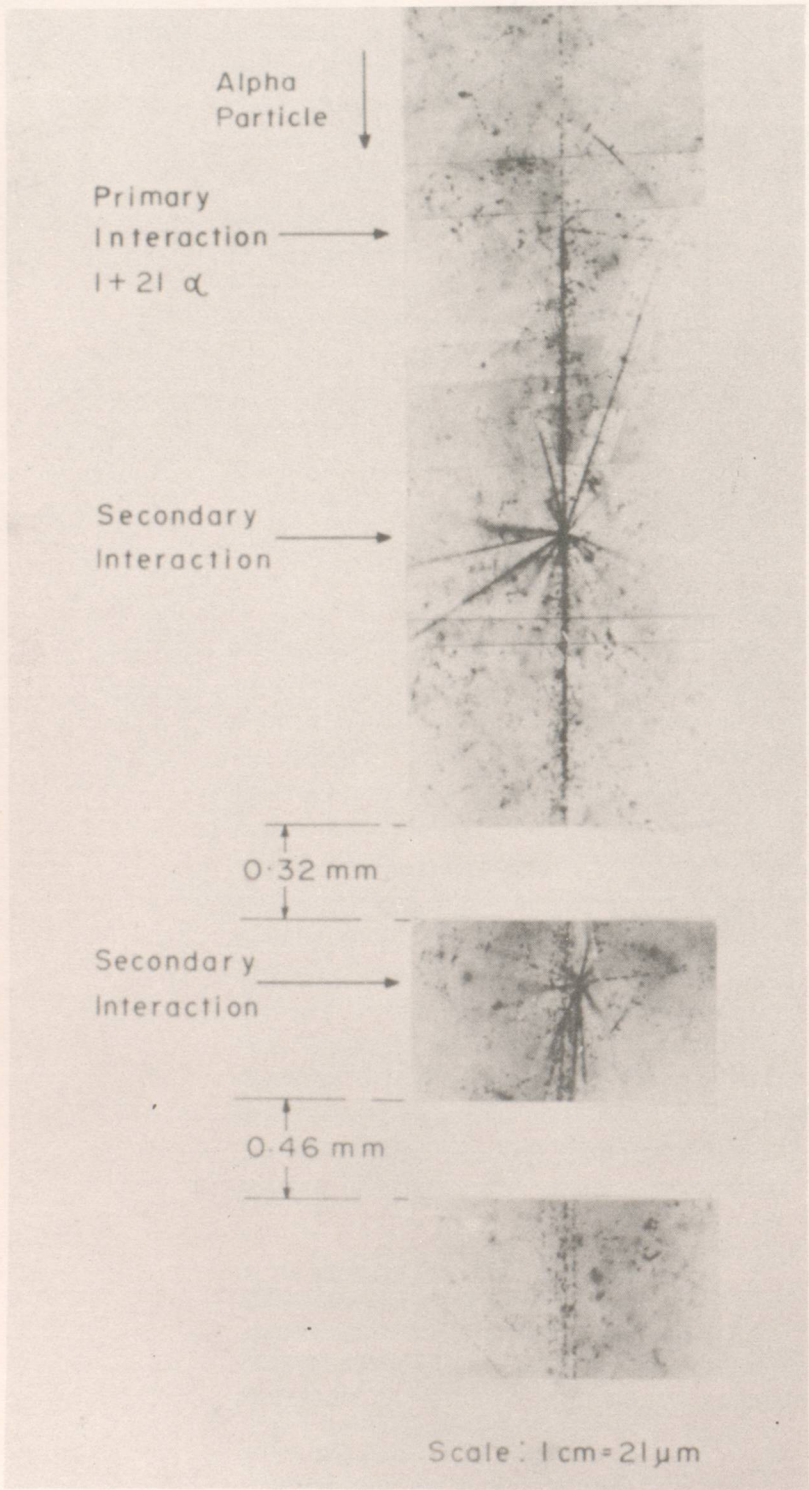


Fig. 2 — An example of a nuclear collision produced by an ultra high energy particle of energy about 10^{13} eV in a photographic emulsion. Of the narrow cone of 21 secondary particles projected in the forward direction from the collision, two have again produced nuclear interactions.

during the course of these studies was the detection, for the first time, of muonic decay of hypernuclei. Some of these investigations would have been severely restricted but for the important studies of the so called spurious scattering which were carried out at the Institute during the previous years.

Considerable effort has also been expended in studying various features of nuclear interactions at energies greater than about 10^{12} eV in cosmic ray investigations using nuclear emulsions. Two major projects need special mention. One involved an international collaboration, known as Schein Stack collaboration,

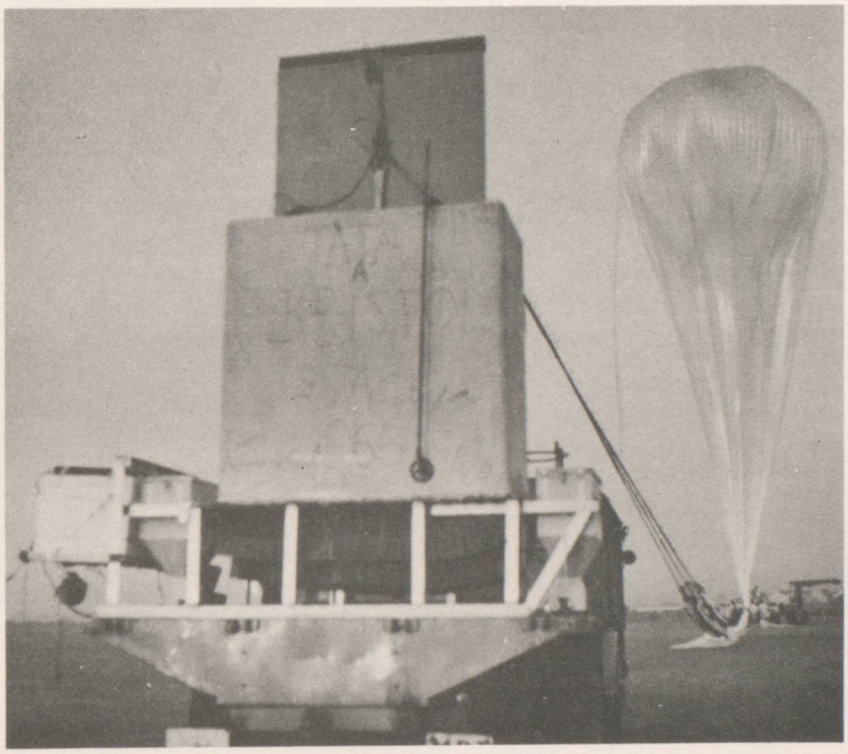


Fig. 3 — The large tungsten-emulsion assembly weighing 700 kg in the process of being flown in a large polythene balloon from Hyderabad in 1961. This exposure was used by the TIFR-Bristol Collaboration for studying nuclear interactions at energies greater than 10^{13} eV.

involving 20 different laboratories, including the TIFR. This enabled, for the first time, large number of so called 'jets' to be collected and analysed in one exposure. The other was a collaboration between the TIFR and University of Bristol, involving an exposure of a massive tungsten-emulsion-graphite assembly at high altitudes in a huge balloon flight over Hyderabad. This resulted in important information on the characteristics of nuclear collisions at energies greater than about 3.10^{12} eV, besides yielding information on the energy spectra of the primary cosmic radiation and γ-rays at balloon altitude.

In the late fifties, the cloud chamber group directed its attention to the study of nuclear interactions in the energy region 20 to few hundred GeV at mountain altitudes. A research station had been set up at Ootacamund (7500 ft altitude) in 1955 where two cloud chambers with lead plates inside were operated for some time for the study of the heavy unstable particles. One of the central problems

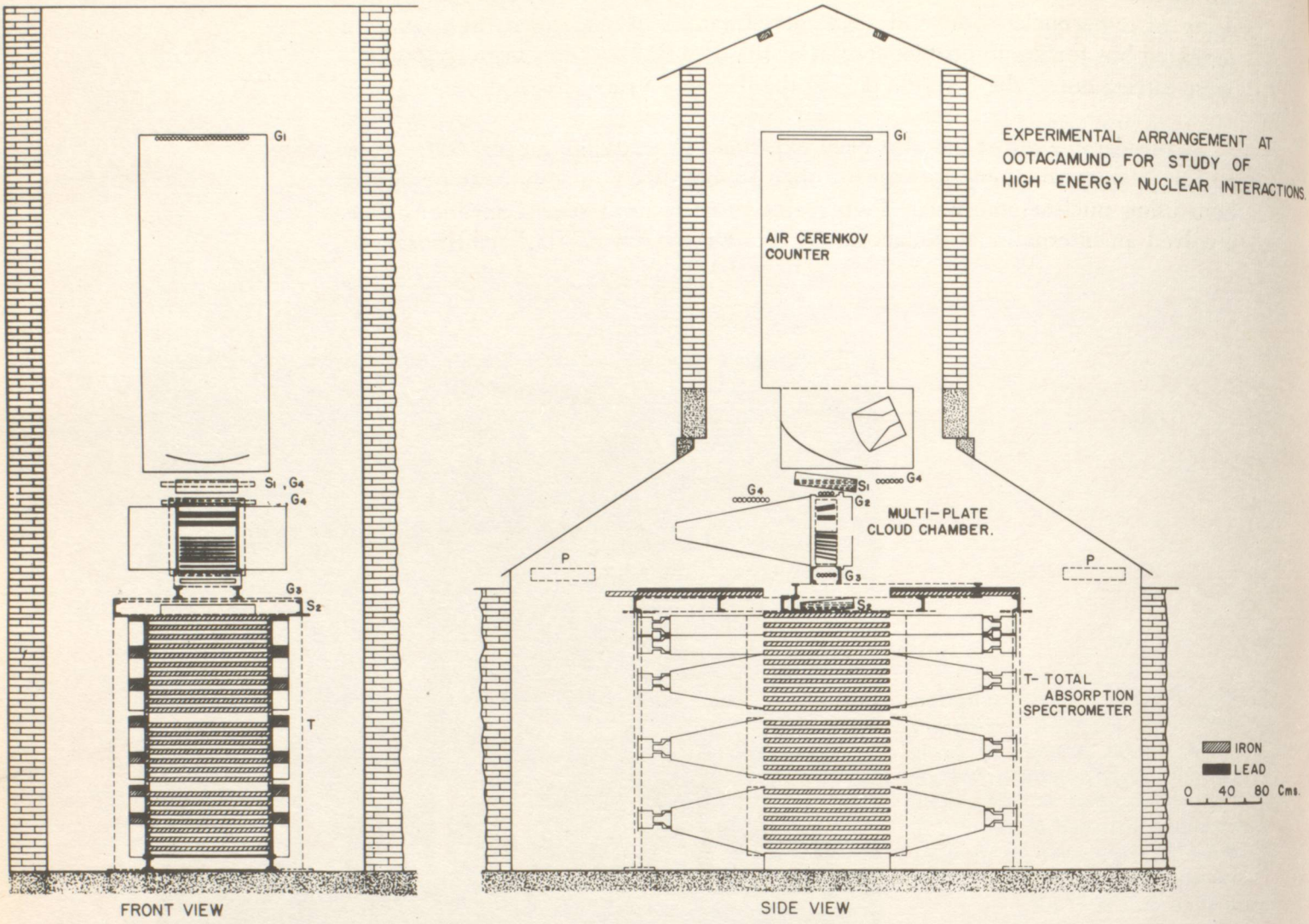


Fig. 4 — An experimental arrangement at Ootacamund to study high energy nuclear interactions. This has three basic elements: (1) an air Cerenkov counter to distinguish between pions and protons of the cosmic ray beam in energy range 10-40 GeV, (2) a multiplate cloud chamber in which the primary interaction occurs and (3) a total absorption calorimeter to measure the energy of interaction products.

encountered in the study of nuclear interactions of cosmic ray particles was the measurement of energies of incident particles. A total absorption spectrometer of iron was built with liquid scintillation counters as sampling media for the measurement of energies of incident particles to an accuracy of ± 20%. At mountain altitudes the strongly interacting cosmic ray particles consist of protons, neutrons and pions. In order to distinguish between protons and pion primaries up to about 50 GeV an air Cerenkov counter was also built. This set-up consisting of a multiple cloud chamber, a total absorption spectrometer and an air Cerenkov counter was a unique one in cosmic ray studies of nuclear interactions at mountain altitudes.

A development parallel to these studies on nuclear interactions of cosmic ray particles with cloud chambers and nuclear emulsions was the study of extensive air showers, which are phenomena induced by cosmic ray primaries at energies greater than about 10^{14} eV. This is the only technique available at present to learn about characteristics of nuclear collisions at these energies although the extraction of parameters of very high energy nuclear collisions from the observed features of these air showers is quite involved. Interesting results on the lateral distribution of electrons, muons and nuclear interacting particles, their energy spectra and the variation of the latter two components with shower size (number of electrons and positrons in a shower at the level of observation) have been obtained. Studies on the time structure of the particles arising in EAS have also been made. Attempts have been made to relate these observed features with model calculations based on the known and extrapolated characteristics of nuclear interactions of high energy particles in air up to energies of 10^{15}-10^{16} eV. In this way, some novel characteristics of nuclear interactions at these high energies have been suggested in these analyses.

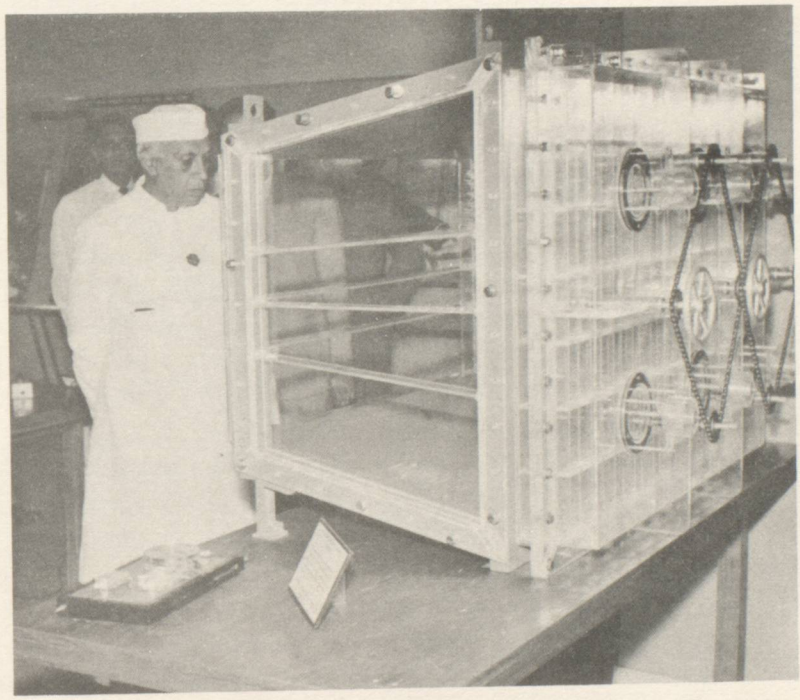


Fig. 5 — A large multiplate cloud chamber (1.5 x 1.6 x 1.0 m^3) operated in Ootacamund. The figure shows the basic structure of the chamber and the expansion system. This has been used primarily to measure the energy and charge/neutral ratio of hadrons associated with extensive air showers.

Thus, at the time of the International Cosmic Ray Conference at Jaipur in 1963, a large number of papers on the characteristics of high energy nuclear interactions studied by means of cloud chamber, emulsion and extensive air shower techniques were reported. The International Cosmic Ray Conference at Jaipur was a turning point in the study of high energy nuclear interactions by cosmic ray particles. While the studies on extensive air showers continued at the Institute with increased vigour,* the cloud chamber and emulsion studies tapered off.

* The biggest cloud chamber in the world was commissioned in 1965 at Ootacamund for these studies and also the total absorption spectrometer mentioned earlier began to be used in this field of investigation. Also studies on the association of high energy muons underground with extensive air showers were initiated at Kolar Gold Fields.

By this time proton accelerators at Brookhaven and CERN had already attained energies up to 30 GeV. the Bubble Chamber techniques used with beams from high energy accelerators proved to be a powerful instrument in revealing a large number of new particles (resonant states) in the domain of strong interactions.

The shift of emphasis in the field of high energy interactions and the possibility of analysing bubble chamber pictures at the Institute with the acquisition of the CDC-3600 computer led a few members of the Institute to switch to this field. Thus in 1967 a group was formed to set up scanning and measuring machines necessary for carrying out experiments with bubble chamber film obtained from accelerator laboratories abroad. At the present time an experiment based on film which was recently exposed for the Institute at the Argonne National Laboratory is being carried out. Another experiment in collaboration with a team at CERN is being taken up this year.

During the course of last twenty years or so, the Institute has made significant contributions in experimental techniques useful in particle physics and high energy physics. To cite only a few, large stripped emulsion stacks, large volume emulsion-metal assemblies, large area triggered spark counter arrays, world's largest multi-plate cloud chamber and magnetic spectrograph have been developed for carrying out research in cosmic ray physics, elementary particle physics and high energy physics.

It should be pointed out that the Institute was always in the forefront in developing and exploiting new techniques and natural facilities available in India for experiments. Thus, for example, the Institute initiated the development of Balloon Flight facility at quite an early stage as it was apparent that a well developed balloon flying capability would enable the Institute to make important contributions on cosmic radiation at high altitudes in equatorial regions. The Institute has acquired great expertise in fabricating and flying special balloons capable of carrying emulsion stacks, massive emulsion metal assemblies or electronic detectors. This coveted facility has enabled the Institute to make important contributions in fields of cosmic radiation, elementary particle physics and high energy physics. India has been fortunate in possessing some of the highest mountains and some of the deepest mines in the world. These facilities have been exploited by carrying out major investigations in Extensive Air Showers resulting from nuclear interactions of cosmic ray particles of energy greater than about 10^{14} eV at Ootacamund, and well-known high energy muon and neutrino investigations at Kolar Gold Fields in Mysore.

It must be pointed out that increasing expertise and size of the groups in different areas of experimental techniques has enabled members of the Institute to conduct experiments of topical interest in the field of cosmic radiation whenever they concerned important questions raised in the field of physics of elementary particles. Thus, for instance, when measurement of intensity on muons very deep underground were carried out for the first time by the members of the Institute at Kolar Gold Fields, the possibility of detecting cosmic ray neutrino interactions deep underground was realised and sophisticated equipment was set up at the Kolar Gold Mines in collaboration with universities of Osaka in Japan and Durham in England. This led to the successful detection of interaction of cosmic ray

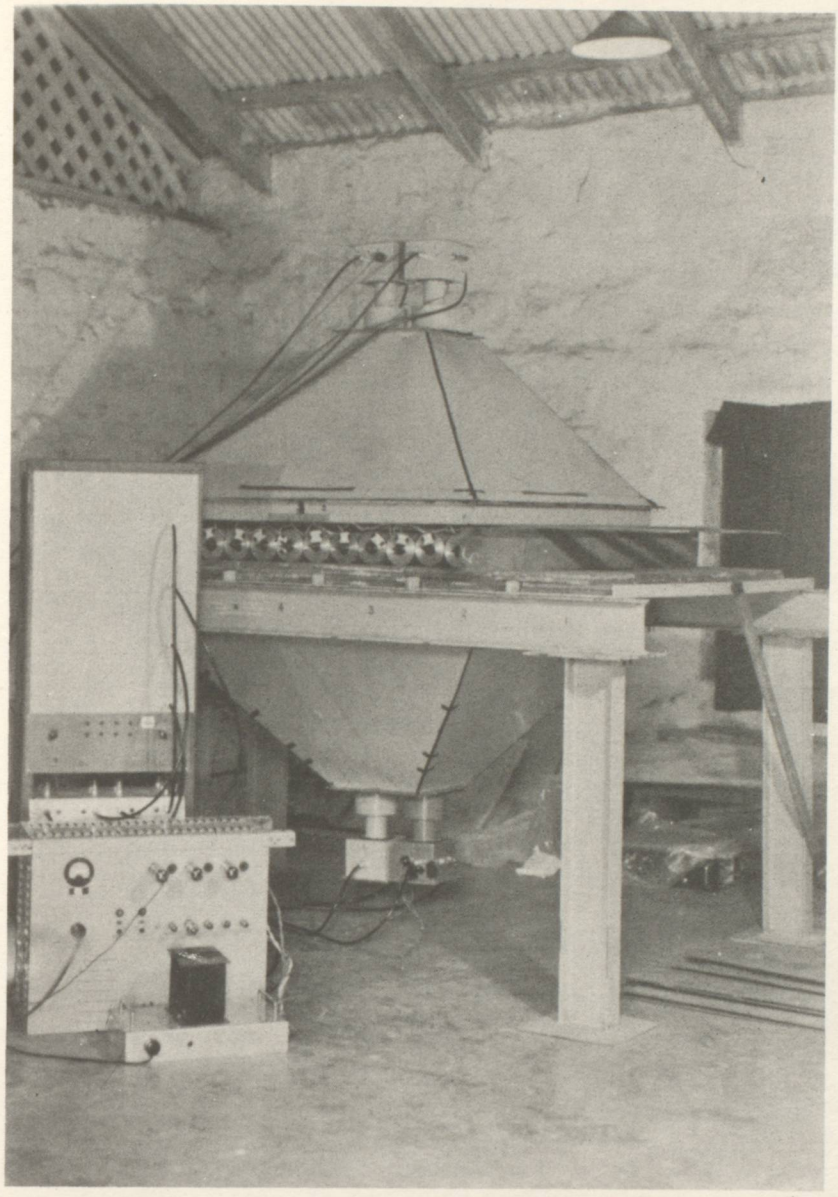


Fig. 6 — A telescope employed for the study of the variation of muon intensity as a function of depth (200-3000 metres) in the Kolar Gold Mines. The telescope was made up of scintillation and G.M. counters interleaved with lead absorbers.

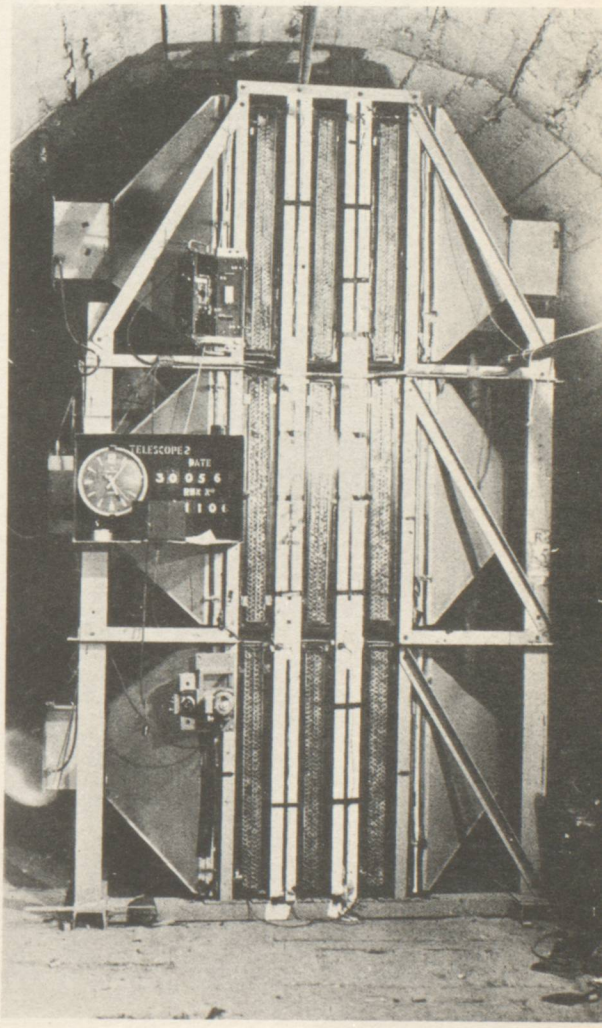


Fig. 7 — A front view of the neutrino telescope inside a tunnel at a depth of 2300 metres m below ground. The basic trigger was provided by pulses from plastic scintillation detectors (housed in light tight cones). The trails of particles were recorded by 3 columns of neon flesh tubes interspersed by lead absorbers.

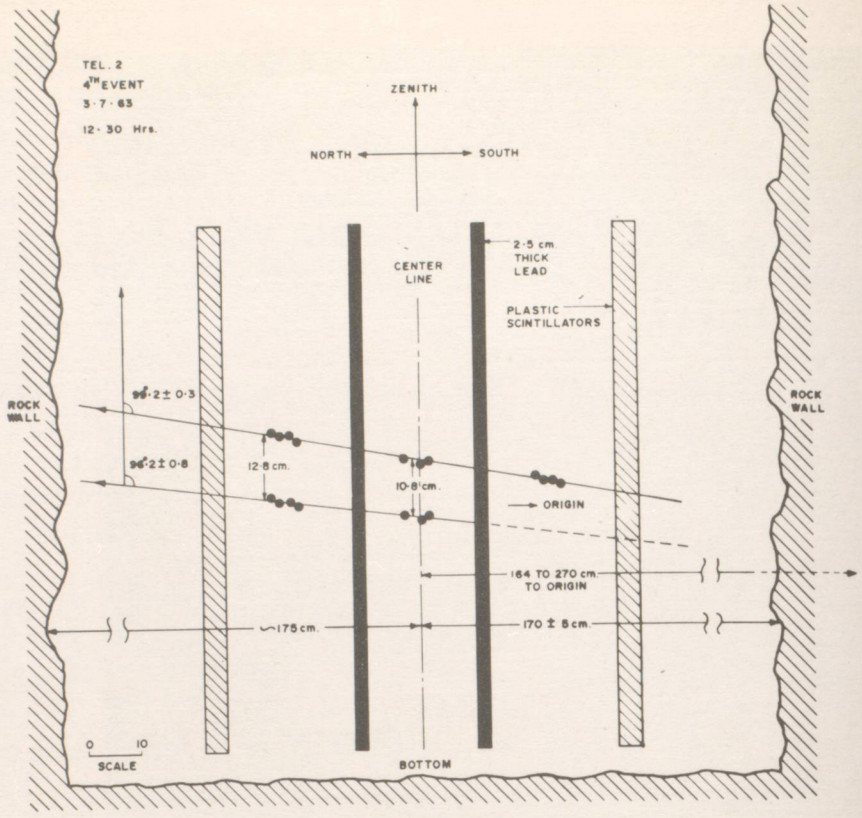


Fig. 8 — A neutrino event recorded in the telescope at the depth of 2300 m. In this example, an upward moving neutrino interacted in the rock wall and the products of interaction i.e. muons or (muon and hadron) were recorded in the detector. This is the first ever inelastic interaction of a natural *neutrino seen in the laboratory.*

neutrinos and to the discussion of the relevance of these observations to questions concerning the variations of inelastic cross sections of neutrino with energy and the existence or otherwise of the intermediate boson, which has been suggested as the quantum for mediating in weak interactions.

Again when the existence of quarks (particles with fractional electric charge), which have been suggested as building blocks of the vast family of strongly interacting particles and resonances, was raised by theoretical physicists, a search for these was conducted in extensive air showers. Another recent investigation at Kolar Gold Fields concerned itself with the angular distribution of muons of energy about 10^{12} eV. Interest in this investigation arose out of a similar investigation by a group at Utah in USA from which it was inferred that a certain fraction of these high energy muons may be produced by some hitherto unknown short-lived (compared to pions and kaons) parent particles. The Kolar results have been found to be at variance with the Utah results.

Future Outlook Thus we see that the field of Elementary Particle Physics has been undergoing rapid developments over the last twenty five years. Contribution to this field

from the Institute so far has come from largely studies made with cosmic ray particles. The rapid increase in the energies of particles produced in several accelerators which have been built has outpaced the cosmic ray investigations in this field. Energies of a few hundred GeV are in sight for accelerators in a couple of year's time. One has also witnessed in this field changes in the experimental techniques. For example the techniques of the Wilson Cloud Chamber and the photographic emulsion has all but been replaced* by bubble chambers and spark chambers for work with accelerators. For active work in this field adaptation to these changes has been necessary. At no time there was any scheme in the Institute for the construction of high energy particle accelerator. An effort in this direction would have meant large scale investments in terms of technical personnel and other material resources incommensurate with the scale of investment in scientific research in this country. Even development of experimental groups to do on-site experiments at accelerators on an international collaboration

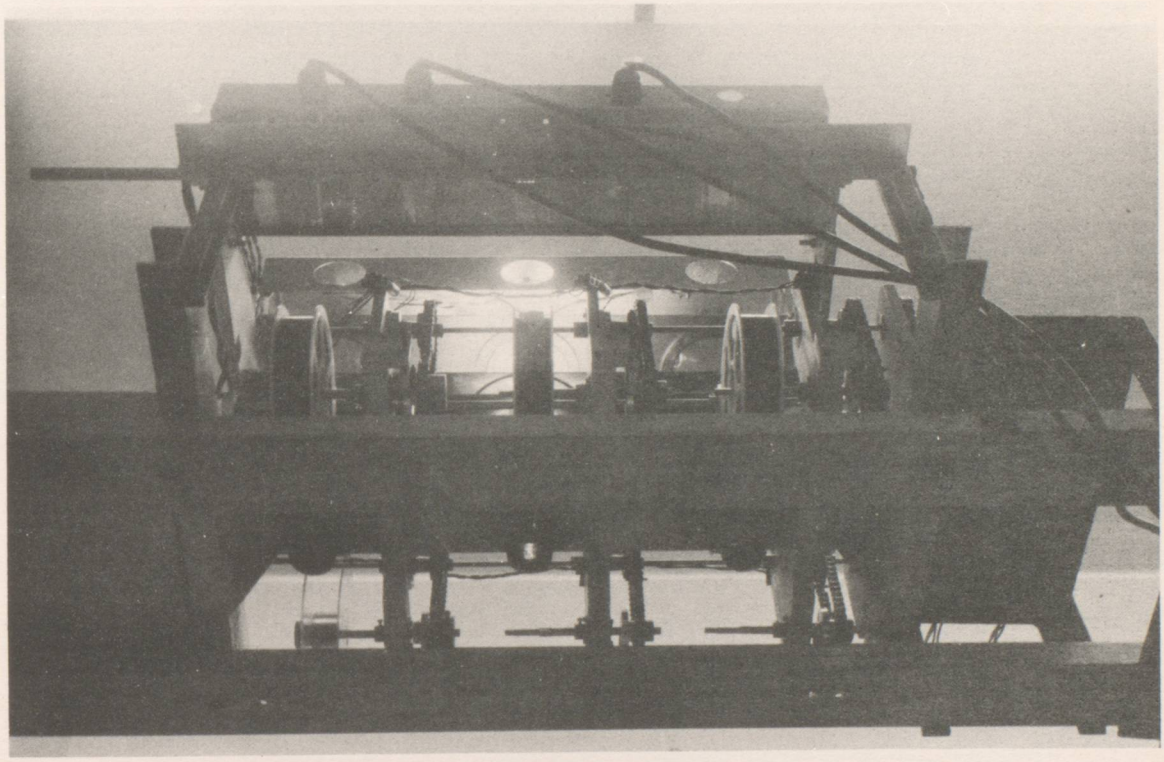


Fig. 9— One of the 4 sophisticated and high precision (50 microns accuracy) measuring machines built at the Institute to digitise trajectories of charged particles recorded in Bubble Chamber films.

basis, though feasible nowadays, would have meant travel and maintenance expenditure of personnel abroad and may have also included contributory expenditure in foreign exchange towards running of a collaborating accelerator laboratory on a collective basis, as is being done for example in Europe at CERN.

* Some limited but interesting information could still be obtained from exposure of nuclear emulsion to particle beams from accelerators. There is for instance a proposal to study γ -rays arising from collision of 24 GeV protons in the CERN intersecting storage rings (equivalent to about 1.5 x 10^{12} eV protons incident on stationary protons) due to be commissioned next year.

However, as there is a *prima facie* case in support of carrying out research in experimental high energy physics because it represents one of the frontier areas of modern physics, efforts have been made to see how best such an activity could be initiated at the Institute.

A careful consideration has led to the belief that it is possible to carry out research work of a high order in the field of high energy physics by setting up a Bubble Chamber film analysis facility at the Institute. In fact in any bubble chamber experiment, the analysis of the pictures is indeed a major effort. Many universities and institutions abroad have facilities for the B.C. film analysis and actively participate in experiments involving exposure of various bubble chambers to beams available at different accelerator laboratories. The modus

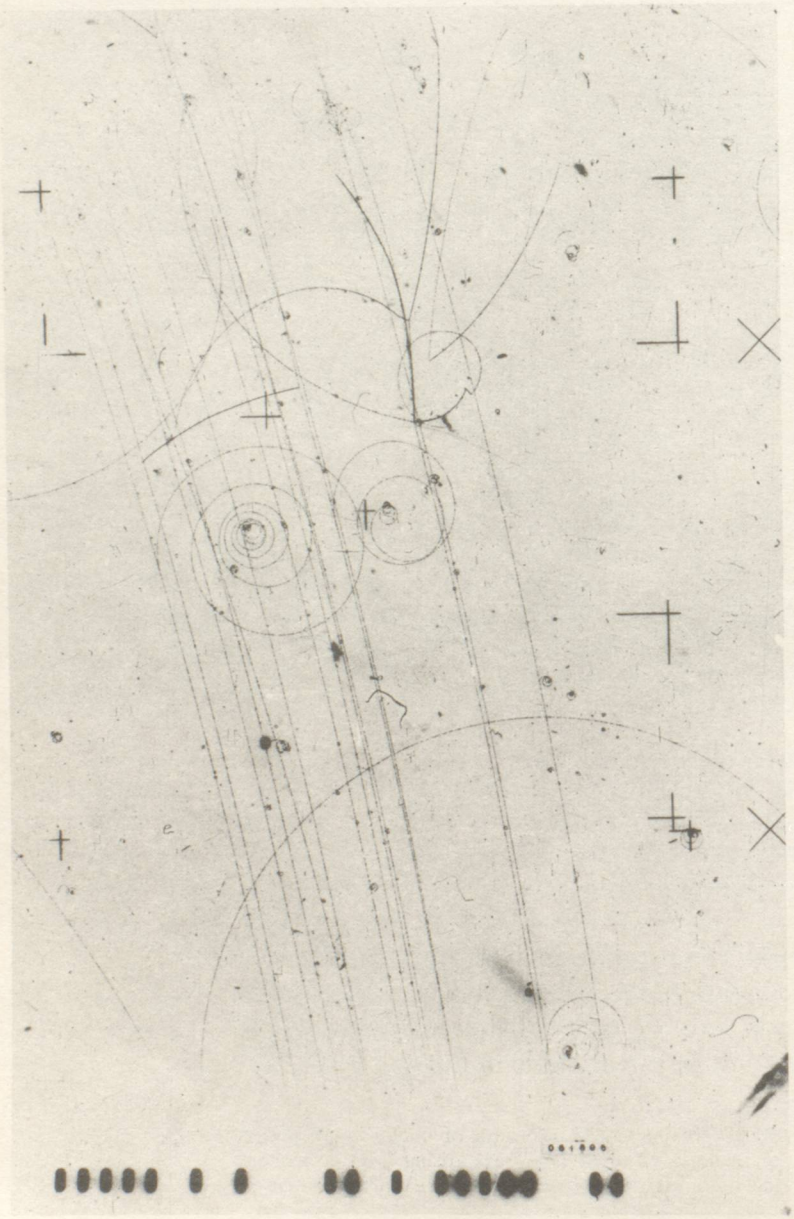


Fig. 10—Nuclear interactions produced by 3.5 GeV/c positive pions with neon nuclei are seen in 75 cm Bubble Chamber filled with a mixture of liquid neon and liquid hydrogen. This is one of 80,000 pictures taken for the TIFR at Argonne National Laboratory, U.S.A.

operandi is that any group interested in exposure submits a well formulated experimental proposal to the accelerator centre which has the required bubble chamber and the particle beam. If the proposal is judged to be a sound one, it is accepted and the requested exposure is permitted.

The highest energy accelerator today is at Serpukhov in USSR, which is capable of accelerating protons to an energy of about 70 GeV. An accelerator with energy between 200-500 GeV is under construction at Batavia in USA and another proposed to be constructed by CERN in Switzerland. These would enable the study of high energy phenomena to be extended to 400-500 GeV. The Intersecting Storage Rings at CERN would make it possible to further extend these studies to an effective energy of about 1500 GeV. It seems probable that for quite some time to come, studies of nuclear processes at energies beyond this will depend upon experiments with cosmic radiation which is known to contain particles of upto at least 10^{20}eV. The Institute is considering plans for a major undertaking to extend its Extensive Air Shower experiments to energy region of $10^{17} - 10^{19}$eV. The chief merit of this proposal is that a large array of detectors would be employed to determine the shower energy more precisely than has hitherto been done in this energy range.

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GEOPHYSICS

GEOPHYSICS

Research activities in Geophysics were initiated at the Tata Institute of Fundamental Research in 1955; two experimental programmes were started, one at the instance of Professor B. Peters, referred to originally as the "Beryllium Project" in the field of cosmic ray produced radioactivity, and the other, at the instance of Professor P. M. S. Blackett, in the field of palaeomagnetism.

Beryllium Project

The objective in the case of the "Beryllium Project" was to look for radioactivity due to Be^{10} in nature; Be^{10} has a very long half-life of 2.5×10^6 years. It was expected that Be^{10} would be produced in the interactions of the primary and secondary particles of the cosmic radiation with the oxygen and nitrogen nuclei in the earth's atmosphere; once produced, the Be^{10} would be brought down to the earth's surface by precipitation and then find its way into the oceans; on account of its very long half-life no appreciable decay would be expected to occur en route, since the time scales of the various processes involved are expected to be small; thus it would accumulate in reasonable concentration in the ocean sediments that are laid down slowly. The long half-life of this nuclide is ideally suited for determining the chronology of deep sea sediments, which are known to hold clues, (in terms of fossil records), concerning the earth's climatic past. Again, Be^{10} being cosmic ray produced would be ideal for determining cosmic ray prehistory over a time scale of several millions of years. In the past, there was no other method that could be conceived for this purpose. In fact, no other nuclear clock can be used for dating events in the late Tertiary (corresponding to the period between now and ten million years ago).

Palaeomagnetic studies

Work in the area of palaeomagnetism had its origin in the realization that studies of the magnetism of rocks from Indian horizons would be particularly valuable in the world network of palaeomagnetic observations for arriving at a judgement concerning the controversial hypothesis of continental drift. This work was taken up in collaboration with a group from the Imperial College of Science and Technology, London; two magnetometers and rock cutting machines were brought from England to start this work here.

Fossil tracks of fast moving heavy nuclei in feldspar crystals from the meteorite "Moore County". Damage caused in the crystal structure due to the passage of heavily ionising nuclear particles, namely, cosmic ray nuclei and fission fragments, can be rendered visible by chemical treatment. Track holes were silver-plated for high contrast viewing. The etching and decoration techniques employed have been developed at the Institute. The field of view is about 35x20 microns.

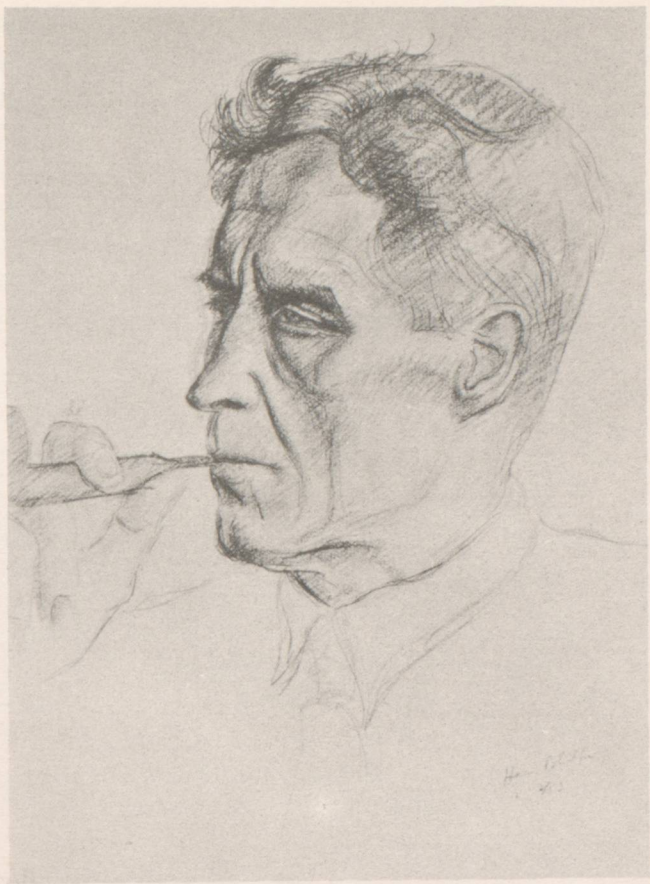


Fig. 1 — A pencil sketch of Prof. P.M.S. Blackett by Homi Bhabha. Prof. Blackett who was a close friend of Homi Bhabha took a special and personal interest in the research programmes of the Institute. Palaeomagnetic studies in the Geophysics Research Group were undertaken in 1955 at his initiative.

Over the past decade and a half these programmes of the Geophysics Group have grown to fairly large proportions and are today concerned with broad areas of earth-sciences and cosmophysics. In the former area, work in progress covers a variety of important disciplines: geology, hydrology, meteorology, oceanography and palaeomagnetism. In the area of cosmophysics, work here covers in general studies of extraterrestrial matter: cosmic rays, meteorites and lunar samples. There are in addition fringe areas of study, such as archaeology, the rate of accretion of gases and of solid objects by the earth etc.

Research programmes in geophysics and cosmophysics based nuclear techniques

Attempts to detect Be^{10} met with success; and in this process a group of scientists was trained in the techniques of microradiochemistry and ultra sensitive low level counting. It also became clear that the technology at hand could be immediately employed to detect several other cosmic ray produced isotopes and naturally occurring radionuclides on the earth. And one could, through studies based on these radionuclides, obtain information about movement patterns, time scales and dates of occurrences of events for which no other methods were available. The nuclear techniques developed by the Institute have opened up wide ranging possibilities in the frontier areas of nuclear geocosmophysics. In order to understand this, it would be instructive to describe briefly the effects of cosmic rays when they interact with matter.

By virtue of their tremendous velocities, cosmic ray particles are capable of breaking up the nuclei with which they collide. The resultant break-up products are various isotopes, both stable and radioactive.

A small proportion of the cosmic ray beam consists of heavy nuclei such as carbon, iron, etc.; and when these go through matter they can produce significant chemical changes in the lattice structure of silicate materials which are present in ordinary rocks, meteorites and lunar materials; this is referred to as *solid state damage*.

Radioisotopes produced as a result of cosmic ray interactions can act as *time markers* in many different ways. The terrestrially produced isotopes exist globally in the atmosphere, in concentrations that can be precisely known, since their production is completely defined by the altitude and latitude variations of cosmic ray intensities and energy spectra, and by the various nuclear interaction cross-sections. They get disseminated from the atmosphere into all the dynamic reservoirs of the earth. They serve as "*tracers*" for large scale motions of air and water, rates of marine sedimentation and a host of *geophysical* phenomena. In the case of radioisotopes produced in meteorites, they are useful for studying prehistoric cosmic ray intensity, and the history of meteorites. The production of radioisotopes in cosmic dust makes it possible to measure the rate of accretion of cosmic dust by the earth during geological periods.

To date, altogether two dozen radionuclides produced by cosmic rays in the earth's atmosphere have been studied. The half-lives of these radionuclides range from about half an hour to few millions of years, and over this time scale they are well spaced apart. Thus it is always possible to pick up radio-isotopes whose half-lives match the time scale encountered in phenomena in meteorology, cloud physics, hydrology, archaeology and oceanography, in which areas, therefore, they can be profitably used.

Twelve of the cosmic ray produced radioisotopes produced in the earth's atmosphere (Be^{7}, Be^{10}, Al^{26}, Mg^{28}, P^{33}, Si^{31}, Si^{32}, Cl^{34m}, S^{35}, Cl^{38}, S^{38}, and Kr^{81}) were detected as a result of work of members of the group. Four of these, Be^{7}, Be^{10}; Cl^{38m}, and Cl^{38}, were independently and nearly simultaneously detected by scientists elsewhere.

One of the radioisotopes which finds a very broad range of applications is C^{14}, which was detected by W.F. Libby in 1948; (for this work Libby was awarded the Nobel Prize for Chemistry in 1960). Other radioisotopes have a less wider application, in one or the other of the earth-sciences; but they mostly do have a unique role as tracers; their world-wide study is limited mainly because of the very sophisticated measurement techniques that have to be employed, which are not easily available to conventional earth scientists.

Besides the detection and detailed study of cosmic ray produced isotopes in different terrestrial reservoirs, work at the Institute has been concerned with a fairly exhaustive theoretical study of the rates of production of isotopes in the atmosphere, in the hydrosphere and in the lithosphere. The experimental

studies, theoretical calculations and the ideas developed in these areas are today recognised all over the world as pioneering and standard reference work.

Important Results

Results in Earth-Sciences

The details, and time scales, involved in the mixing of air within the atmosphere, both vertically and latitudinally have been studied in depth with the help of natural and artificial radionuclides. For this the concentration of various isotopes has been determined both in the air masses as well as in precipitations. It has been established that the time scales of the various processes studied, such as exchange of air across the tropopause, north-south mixing within the stratosphere and in the troposphere, and rate of wash-out of aerosols from the troposphere by wet precipitations, range between two weeks to a few years.

A very novel method based on radon, (half-life: 3.8 days), as a tracer, has been developed and successfully employed to delineate the course of movement of the Indian South-West monsoon.

Cosmic ray produced Si^{32} activity has been successfully employed to study the ages of ground waters younger than 2000 years.

In the field of oceanography, besides successfully dating old sediments using Be^{10}, the radionuclide that launched the geophysics programmes of the Institute, several marine phenomena have been investigated in detail. These include: rates of accumulation of biogenic silica-rich sediments based on Si^{32}; growth of manganese concretions, (commonly referred to as manganese nodules), based on the nuclides Be^{10} and Io/Th; details and rates of mixing of water in a vertical column in the ocean, based on Si^{32}; and geochemical behaviour of a suite of trace elements in the oceans.

Results in Astrophysics

In the field of *astrophysics*, the intensity of "galactic" and "solar" cosmic radiation during pre-historic periods has been deduced, through studies of meteorites, and more recently of lunar materials. Both *radioactivity* and *solid state damage* produced by cosmic rays in these *extra-terrestrial materials* have been investigated. It has been shown that during the past 5×10^6 yrs. the galactic cosmic ray intensity has remained the same, (within a factor of 2), as today. Solar cosmic radiation is a sporadic phenomenon; but it has been possible to deduce its time-averaged flux over a period of upto million years.

Meteorites and the lunar surface can be considered as being sensitive detector systems which have been exposed for extended periods of time to cosmic rays, and which contain as a result the fossil records of the traversals of large number of cosmic ray particles with different charges and energies. New techniques have been developed at the Institute for revealing these fossil tracks in silicate materials by chemical etching. And through a study of these tracks, it has been possible to obtain accurately the chemical composition

of the cosmic ray beam, and the extent of ablation in meteorites caused during their high speed traversal through the earth's atmosphere. Results are now accumulating rapidly on the energy spectrum and chemical composition of heavy nuclei, in the cosmic radiation during prehistoric periods (last 10^6-10^7 yrs.). Studies of fossil tracks in Patwar, St. Severin and a few other meteorites have provided high resolution data on the time averaged energy spectrum and chemical composition of iron group nuclei at 2-3 astronomical units. The relative flux values for *very heavy* nuclei (2 greater than 30) have also been determined. Extensive investigations of fossil tracks in Kapoeta and other so called gas-



Fig. 2 — Fossil cosmic ray tracks in a large feldspar crystal, (about 1 mm across), from the meteorite, "Kapoeta". Though this crystal is from the inside part of a large meteorite, it has a relatively high density of fossil tracks, indicating that prior to the compaction and creation of this meteorite in its present form, a part of the matrix was exposed to the cosmic radiation.

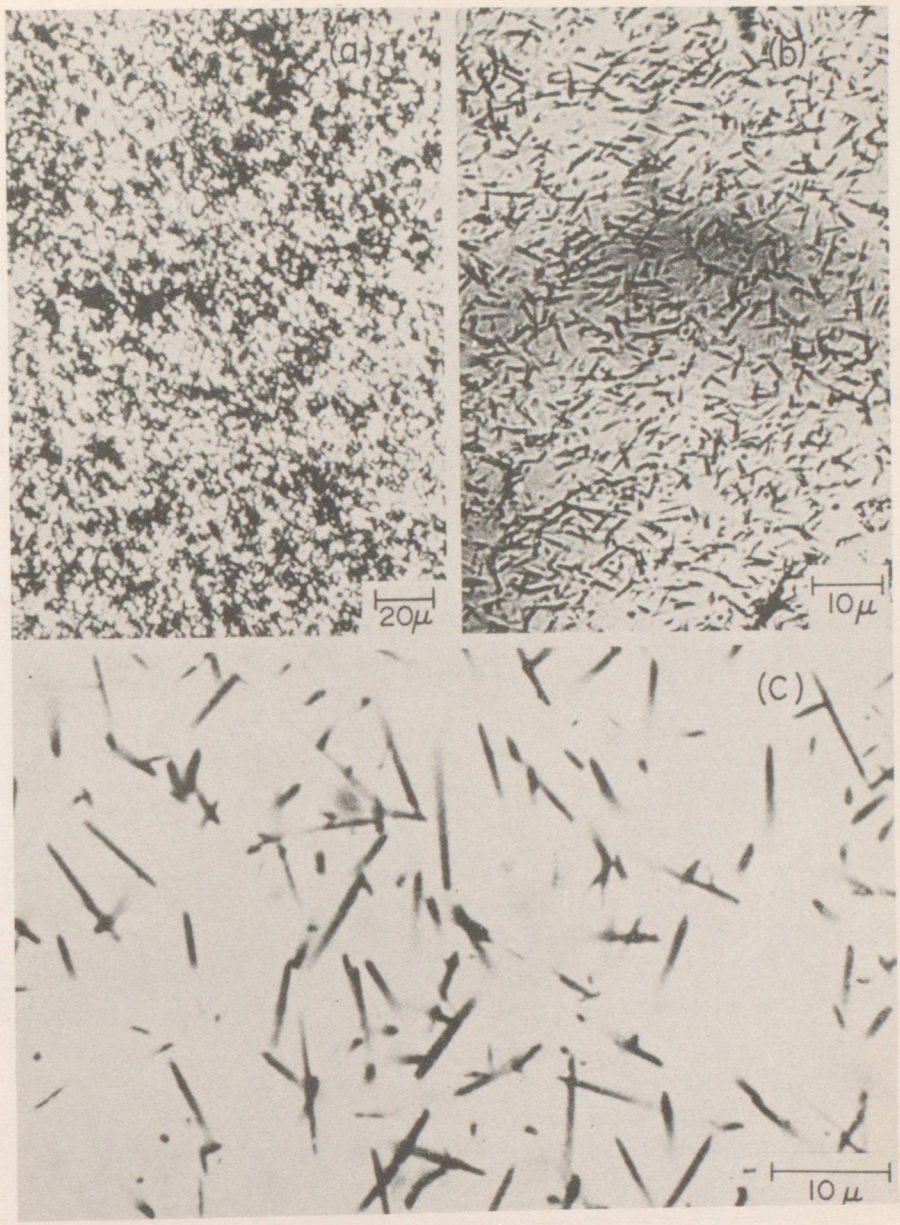


Fig. 3 — A close-up view of fossil tracks in a "Kapoeta" pyroxene crystal. The rapid decrease in the density of tracks as one moves away from the crystal border is clearly noticeable. Such a situation would be expected to arise from an exposure of the crystal to very low energy iron nuclei of the cosmic radiation.

rich meteorites have provided unique evidence for the low energy bombardment of individual grains in space before their compaction. Since October 1969, lunar samples returned on the Apollo 11 and 12 missions have been studied to learn about the pre-history of cosmic radiation as well as the radiation history of lunar samples (rock and dust) in the regolith.

Super-heavy elements

Besides its applications to cosmic ray physics, the fossil track technique has been applied successfully for investigating the existence of (the now extinct) transuranic elements in primitive solar system materials. The results obtained strongly suggest the very likely existence of not only Pu^{244} but also the very very heavy elements of charge 115 and mass 300 in both lunar and meteorite samples. Such super-heavy elements have not as yet been synthesised in the laboratory.



Fig. 4 — Photomicrographs of the variety of tracks in silicate crystals as seen in meteoritic and lunar samples. In favourable cases, observations of tracks in a small grain of meteorite or lunar rock/dust, weighing less than a microgram, reveal the fossil records of a few hundred cosmic ray nuclei.

The acceptance of the Institute by the National Aeronautics and Space Administration, USA as a prime investigator for analysis of lunar samples is a recognition of the pioneering work already carried out here in these fields.

Techniques

To carry out these programmes, it has been necessary to develop extremely sensitive low-level counting techniques for β^-, β^+ and γ radiation. Low-level counters developed by members of this group for counting beta radiation of solids are now commercially available in USA. It has also been necessary to develop new radio-chemical methods. The successful development of a simple technique for *in-situ* extraction of a variety of elements present in trace quantities in the oceans from large volumes (100-1000 tons) of sea water has opened up new possibilities in realms of nuclear-oceanography. Equipment based on a method developed here for synthesising methane from water and carbon dioxide—which

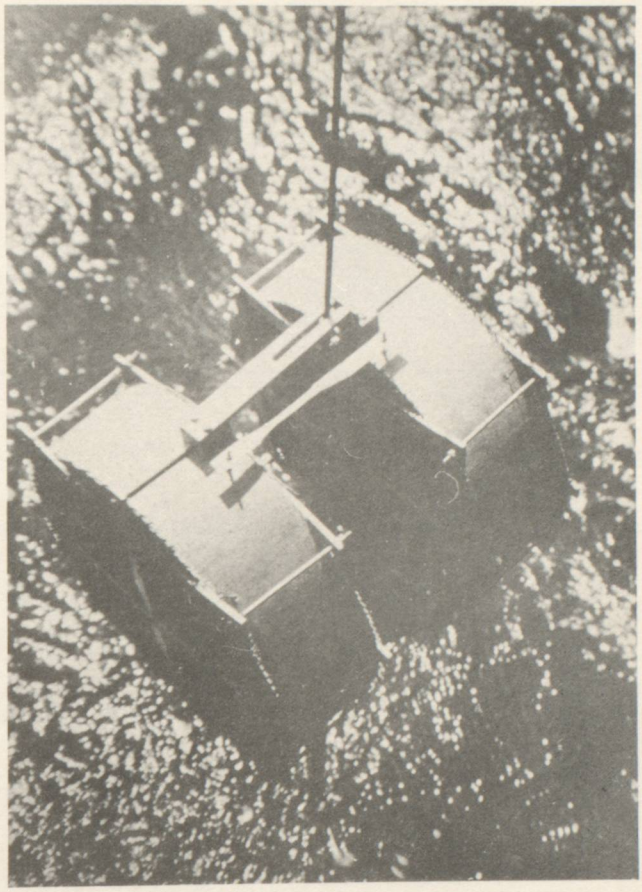


Fig. 5 — The twin stainless steel sampler shown here contains specially treated natural sponges. This sponge matrix is capable of in-situ extraction of elements present in trace concentrations in sea water; this technique was developed at the Institute.

is very valuable for work involving tritium and radiocarbon—is now commercially sold in USA.

Overall scope of work in nuclear geophysics

A schematic diagram showing the various areas of earth-sciences and astrophysics/cosmochemistry studied to date by the Geophysics Group is shown in Fig. 6. The principal *cosmogenic/natural series/man-made radio isotopes* used for the different studies are shown in this figure.

Palaeomagnetism

The Gondwanaland hypothesis put forward by du Toit and Wegener around 1925 postulated, on the basis of geological evidence, that approximately 200 million years ago India, South Africa, the east coast of South America and the west coast of Australia were grouped together close to the south geographic pole. Other evidence, based on the present day contours of these continents and stratigraphic correlation of fossil and rock types found in these land-masses lend support to this hypothesis. Rock magnetic measurements made in Europe, America and in other countries during the last decade have also given strong indications for continental drift. They show that either the earth's crust had slipped over the outer layers of the mantle or that the continents had moved relative to each other or that a combination of both processes had occurred. The geographic

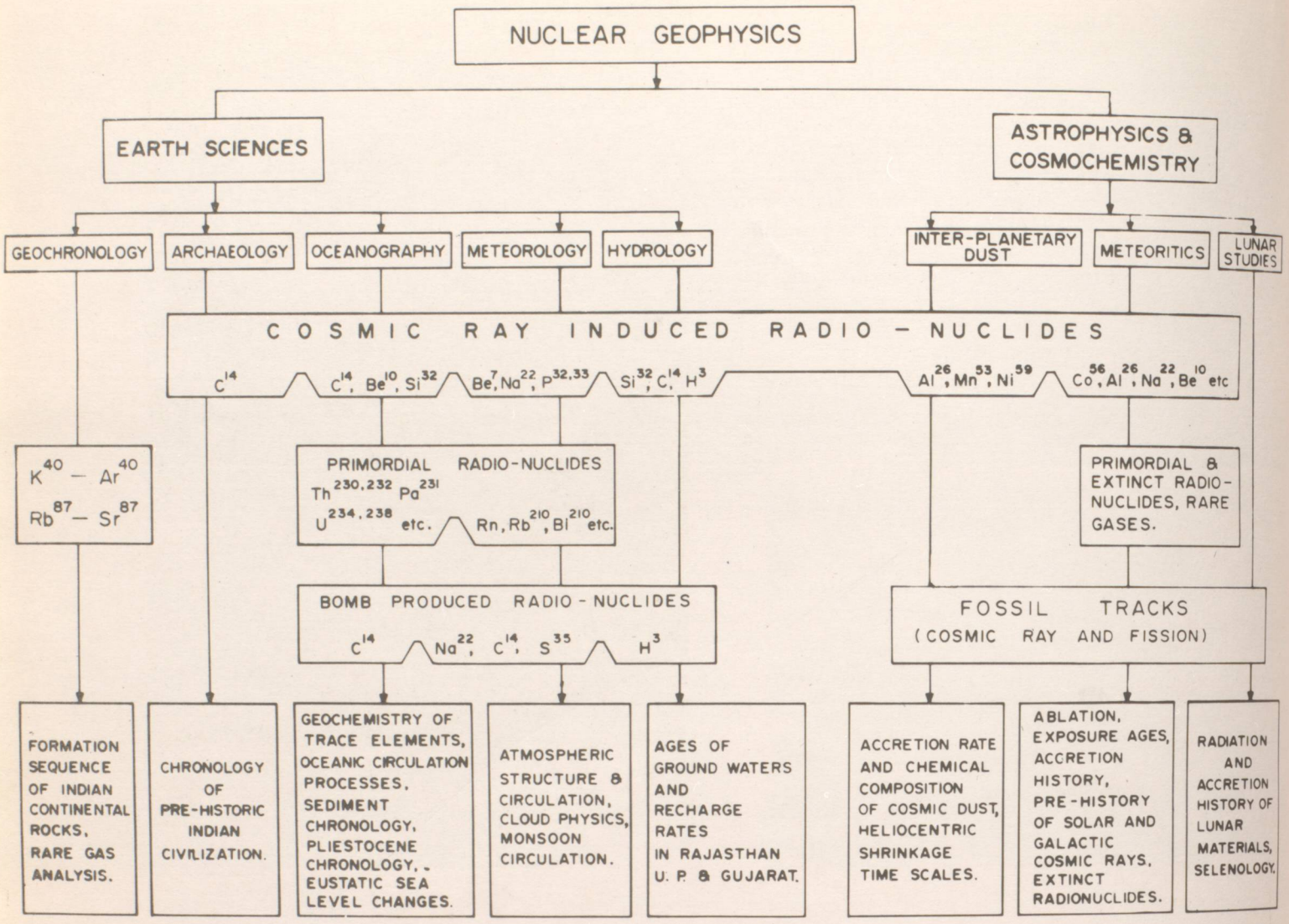


Fig. 6 — Research programmes that have been undertaken in the area of "Nuclear Geophysics" are schematically shown. Some of the "cosmic ray produced", "primordial" and "bomb produced" radionuclides which are used for studying earth sciences are indicated. Several of the techniques with geocosmophysical applications, based on the interaction of cosmic rays with matter, (production of radioisotopes and solid state damage), were first initiated or developed at the Institute.

position of India, which on the hypothesis of continental drift had moved from near the south pole to its present position, well north of the equator, and the existence of laval flows covering widely different geological epochs makes India a fairly unique location for studying the nature of continental drift in the past. If this hypothesis was correct one would expect to find evidence for a particularly large shift in latitudes for rocks in India which were formed around 200 million years ago.

Studies of the fossil records of the earth's magnetic field, a field designated as palaeomagnetism, were successfully carried out at the Institute between 1955-1961, and have covered a wide range of Indian rock horizons. The data obtained here strongly support the hypothesis of continental drift. Additionally, definite evidence has been obtained for periods of reversal of the geomagnetic field. This group has also been concerned with a determination of the intensity of the earth's magnetic field during the last 4500 yrs., based on a study of "archaeomagnetism" i.e. fossil records of the earth's magnetic field, seen in artifacts (pottery, kiln etc.) from archaeological sites.

Rock-magnetism

Since 1961, the programme of this group has been oriented towards a study of the basic properties of rocks as magnetic substances; this area is often referred to as "rock-magnetism". For elegant and detailed studies of the magnetic properties of rocks, the group here has designed and built a hysteresis loop tracer and magnetic susceptibility measuring unit; these are now being marketed commercially by the Electronics Corporation of India Ltd., Hyderabad. Some of the important results obtained in this field are: (i) observation and classification of hysteresis loops of basalts; (ii) discovery of a new type of magnetic memory phenomenon in basalts arising through an interaction among clusters of single domains; (iii) observation of "single domain effect", which is somewhat similar to the Hopkinson effect, and other magnetic phenomena associated with single domains. Most of these results can be elegantly demonstrated in the laboratory using instruments developed by the group.

National facilities run by the Geophysics Group

The principal interests of the Geophysics Group have been in the fundamental areas of cosmogeophysics. In order to carry out meaningful studies in these areas, it has been necessary to develop powerful techniques. The policy of the Institute has always been that wherever possible such techniques should also be applied to solve problems in other areas of national interest and relevance. Accordingly, the Geophysics Group has set up two laboratories which operate as National Facilities: (a) A Radiocarbon Laboratory for studies in Indian archaeology; and (b) A Laboratory for Hydrology, in which use is made of the radioistopes H^3, Si^{32}, and C^{14}, for ground water studies in the country. Both these laboratories have been functioning since 1961. It might be argued that it would have been more appropriate for such laboratories to be started and to be run by organisations more closely connected with the areas of application, namely, archaeology and hydrology. The answer to this is that any successful use of these sophisticated nuclear techniques involves skills in electronics, vacuum technology, nuclear physics and nuclear chemistry; these are easily available at the Institute on account of the other programmes being pursued by the Geophysics Group for which they are essential. Experience elsewhere in the world has shown that such laboratories when operated without the appropriate base are unable to generate and to maintain the standards needed. It was therefore felt that the Institute should put in the effort to set up and operate these facilities in the national interest. Details relating to the set up and the organisation of the Radiocarbon Laboratory and the Laboratory for Hydrology are given separately in this Report.

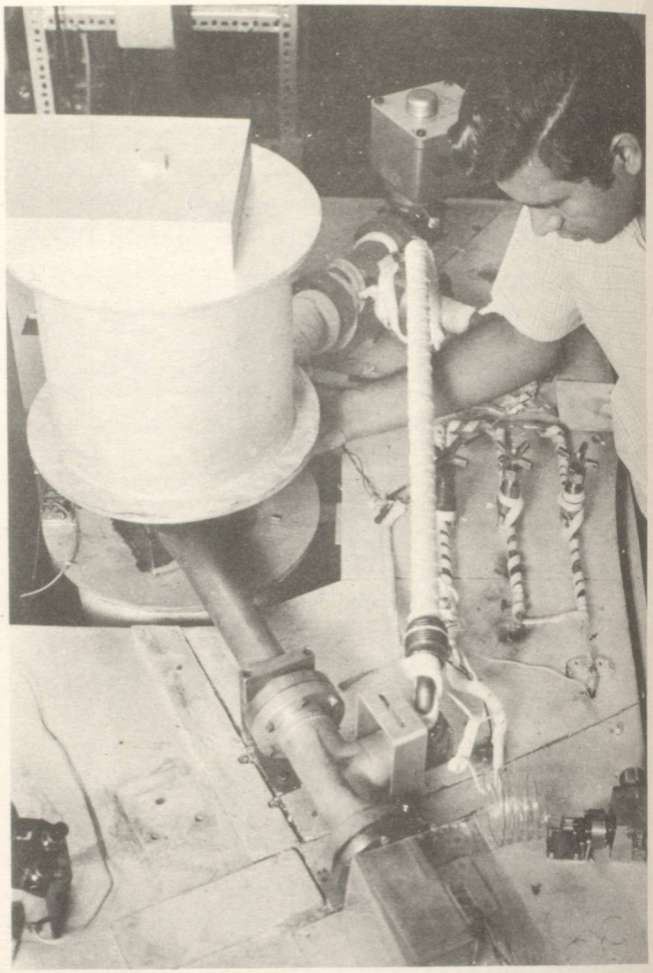


Fig. 7 — A view of the 9" radius mass-spectrometer. The instrument can accept a gas or a solid source for dating rocks by K-Ar and Rb-Sr methods, respectively. The instrument was given to the Institute on an indefinite loan by the Carnegie Institution in Washington and is now being used for K-Ar dating of young basaltic rocks from the Deccan Plateau. Two more mass-spectrometers for the analysis of ultra-small gas and solid samples are now under fabrication in the Institute to investigate extra-terrestrial samples.

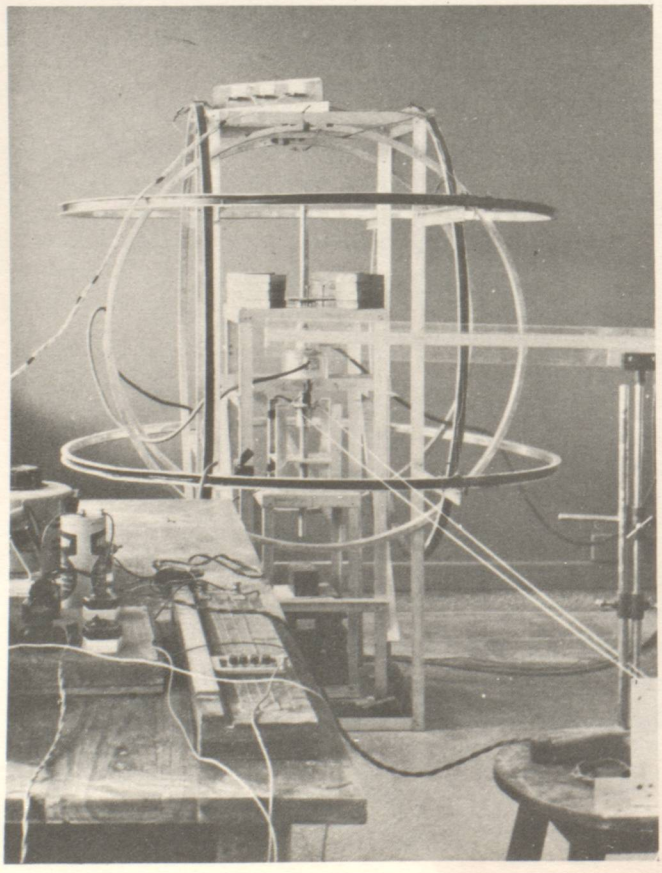


Fig. 8 — An astatic magnetometer with a built-in non-magnetic furnace allows the measurement of very weak magnetic fields as a function of temperature: remanent magnetisation in rocks and oceanic sediments at levels of 10^{-7} e.s.u. can be easily measured. The instrument was built at the Institute; the original design of the astatic magnetometer is due to Prof. P.M.S. Blackett.

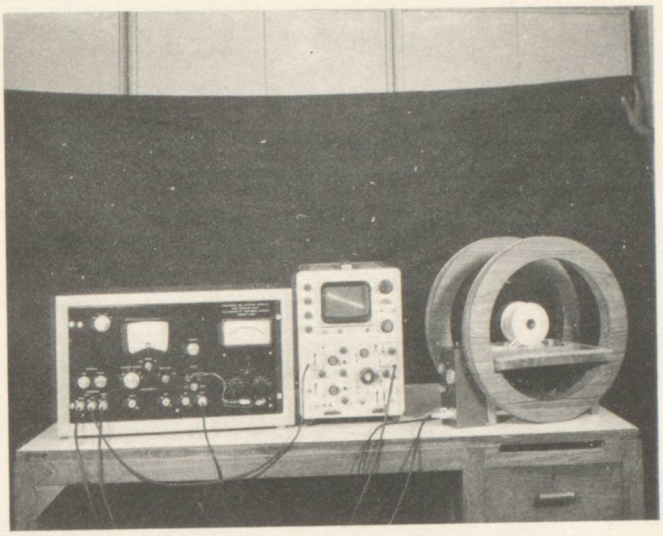


Fig. 9 — Apparatus used for measuring "susceptibility" and "hysteresis" of a variety of materials including paramagnetic substances. This instrument, which was designed and developed at the Institute, led to the discovery of a new kind of magnetic memory phenomenon in basalts, presumably arising due to the different states of aggregation of fine single domain grains.

Concluding Remarks

It has been a great adventure for the members of the Geophysics Group to apply the techniques of nuclear physics/chemistry to problems of cosmogeophysics and geomagnetism, and to problems closely related to economic and cultural elements in the country. The work of the group has clearly demonstrated the unique possibilities inherent in the application of such techniques to *geology, geophysics, oceanography, meteorology, hydrology, archaeology, cosmic ray physics,* and the *history of minor and major objects in the solar system.* The problems studied so far seem to mark just the beginning and several new and exciting problems in these very diverse branches of science still remain to be explored.

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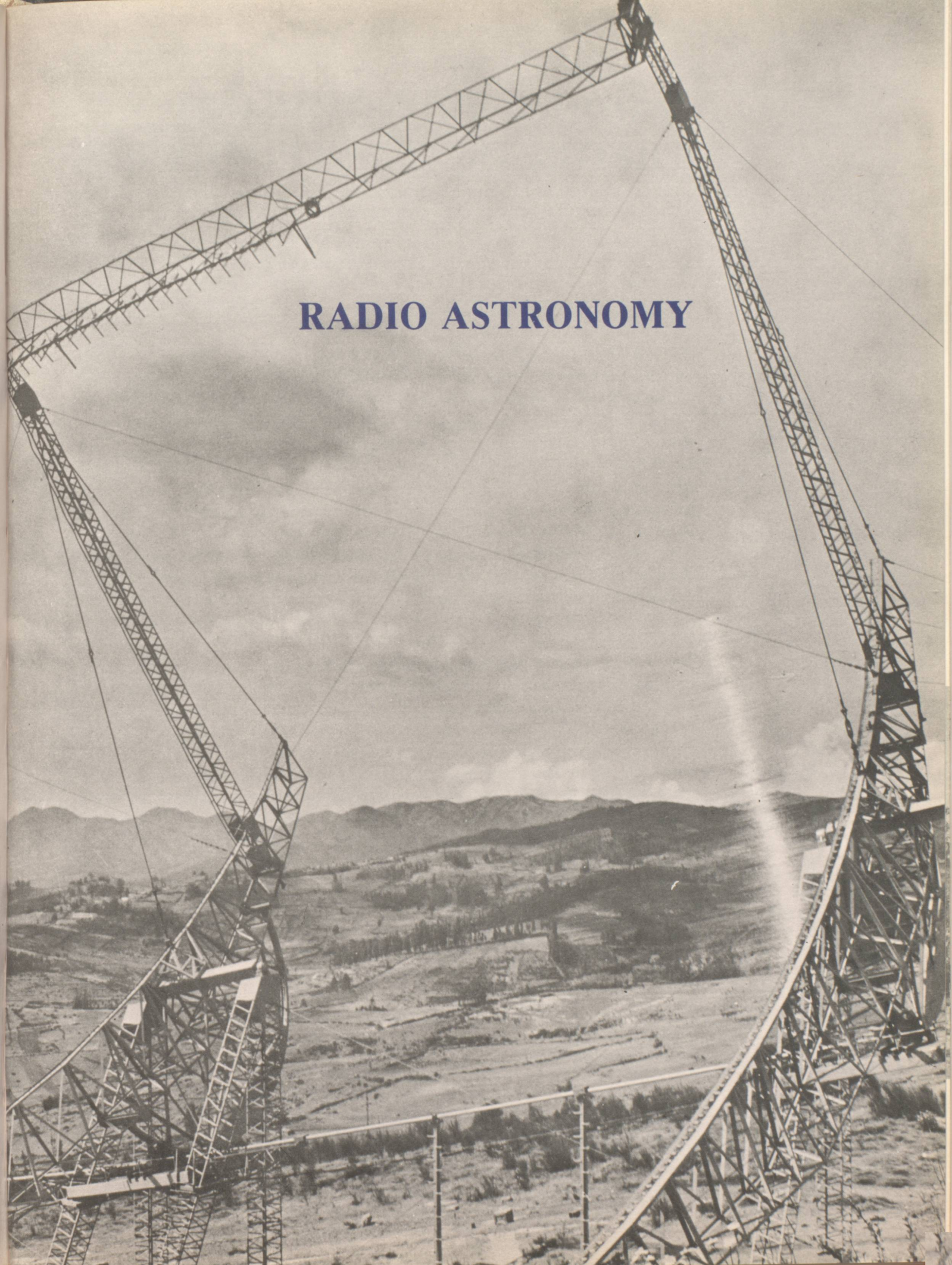
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RADIO ASTRONOMY

RADIO ASTRONOMY AND THEORETICAL ASTROPHYSICS

The New Science of Radio Astronomy

Radio waves from an extraterrestrial source were first detected in 1932 by Karl Jansky who recognised that the Milky Way is a source of strong radio emission. Rapid progress in the field became possible only after 1945 through exploitation of radar technology developed during the second world war. Within the following decade, many remarkable discoveries were made which established the potential of radio astronomy and made a deep impact on almost all areas of astronomy. The detection of radio emission from solar corona and particularly the discovery of several types of solar radio bursts gave a new understanding of the solar plasma, of considerable importance to the studies of solar-terrestrial relationship. The radio studies of the historical supernova remnant, the Crab nebula, revealed that such explosive events give rise to highly energetic electrons which emit radio waves as they spiral in magnetic fields at relativistic speeds. The discovery of 21-cm line radio emission from neutral hydrogen in 1951 launched a new era of studies of the galactic structure, leading to the identification of spiral arms in our Galaxy, which had remained obscured to the optical telescopes due to the intervening dust. Several strong radio sources were found to be associated with distant galaxies. Detailed studies of the radio galaxies brought a startling realization that a significant fraction of their entire rest mass energy is in the form of relativistic particles and magnetic fields. It seems that about one in a million galaxy is a strong source of radio waves. Quasars are even more remarkable as intense emission originates in very compact cores of energetic galaxies. The colossal energy release is perhaps due to gravitational collapse of nuclear regions, but the origin and cause of these explosive events remain a matter of considerable speculation. Being highly luminous at radio wavelengths, these galaxies are observable up to much larger distances in the radio as compared to optical regions. Therefore, radio astronomy has also made many valuable contributions to studies of cosmology.

The use of radio window has greatly widened our perspective of the Universe because bright radio emission in cosmic objects arises due to physical processes that are different from those responsible for optical emission. The chain of exciting discoveries continues to grow with the improvement in sensitivity and resolving power of radio telescopes as well as diversity of the techniques

A close up view of the Ooty Radio Telescope showing 2 out of 24 parabolic frames. The curved light streak shows reflection of sunlight from stainless steel wires of 0.38 mm diameter forming the reflecting surface.

used, such as aperture synthesis interferometry, very long baseline interferometry, low noise receivers, digital correlation, etc. The detection of the universal 3° K microwave background by Penzias and Wilson in 1965 provided a strong support for a big-bang origin of the Universe. The dramatic discovery of pulsars in 1968 by Hewish and Bell at Cambridge, which emit electromagnetic pulses at incredibly regular intervals of a fraction of a second, confirmed theoretical prediction of the evolution of a massive star into a neutron core. Recent theoretical and experimental work on black holes has elucidated new physical concepts in the domain of highly condensed matter. Radio frequency lines have been found from many clouds of complex organic molecules. These pervade the inter-stellar space widely and are believed to be the precursors to the formation of stars. Since such molecules are also thought to be the basic constituents from which life evolved on the Earth, their detection far beyond our solar system has raised the possibility that life may be widespread in the Universe.

The Beginning of Radio Astronomy at TIFR

In 1961, several Indian scientists working in the field abroad approached TIFR, UGC, CSIR, etc. for the formation of a group in India. TIFR seemed a good choice because of its considerable interest and contributions to the field of Cosmic Rays. With the encouragement of Dr. Bhabha, a group was formed at the Institute in 1963 with the objective of establishing a major experimental facility.

As a first step it was decided to set up a high resolution interferometer for studying the Sun at Kalyan near Bombay. For a long term project, several new possibilities were examined rather than following existing fashionable ideas. The aim was to conceive a low-cost yet a powerful telescope, specially designed for answering some outstanding problems. This search led to a novel proposal for construction of a large steerable radio telescope consisting of a parabolic cylindrical antenna mounted on a hill slope such that its axis of rotation becomes parallel to the rotation axis of the Earth. This allows a celestial object to be tracked from horizon to horizon by a simple mechanical rotation of the antenna from east to west. This concept utilizes India's location near the geographic equator. After an intensive search an appropriate hill was located at Ootacamund in South India. Work on the Ooty radio telescope was started in late 1965 and was completed by 1969 end. In addition to scientific gains, these activities also triggered and nurtured development of a major antenna industry in India.

The Kalyan Radio Telescope

The radio interferometer was designed for making solar observations at 610 MHz with a resolution of $2'.3$ arc in the east-west and $5'.2$ arc in the north-south direction. It consisted of 32 parabolic dishes of 1.8 m diameter located over a baseline of about 630 m in the east-west and 256 m in the north-south

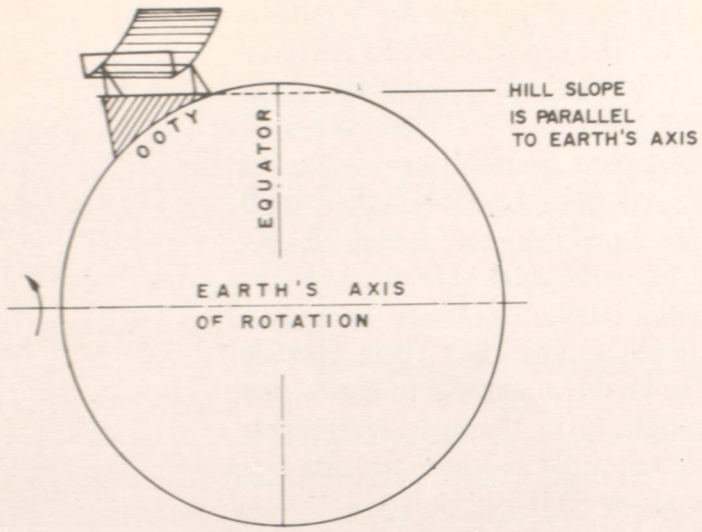


Fig. 1—Basic design concept of Ooty Radio telescope.

direction. These dishes had been obtained in 1957 by National Physical Laboratory from Australia under Colombo Plan, after Christiansen's interferometer near Sydney was closed down. The operating frequency of the Kalyan interferometer was 610 MHz, which was chosen because there existed considerable uncertainty about the characteristics of solar emission at decimetre wavelengths. The work on Kalyan interferometer was started in late 1963 and it was put into operation by June 1965. It was first used to make a two-dimensional map of the quiet sun at 610 MHz. It was found that the radio sun has an elliptical shape with limb-brightening seen near the equatorial regions, in conformity with observations at optical and shorter radio wavelengths. The limb-brightening at this long wavelength indicated absence of strong scattering in the inner solar corona. An electron temperature of about 1 to 1.5 x 10^6 °K was estimated for the solar corona. The brightness temperatures of the radio components identified with solar bursts were found to lie in the range of 10^6 to 10^8 °K. The sources of the slowly varying component were well resolved with the 2′.3 x 5′.2 beam and their brightness temperature was found to be correlated with sunspot area.

The Ooty Radio Telescope

This giant radio telescope is located at Ootacamund amidst the picturesque Nilgiri hills and is one of the largest radio telescopes in the world. It consists of a parabolic cylinder of size 530 x 30 metre, whose reflecting surface consists of 1100 parallel wires mounted on 24 parabolic frames. Operating at a frequency of 327 MHz, the telescope has a collecting area equivalent to a 140-metre paraboloidal dish. The novel feature of the antenna is that its long axis has been located on a hill whose slope in the North-South direction is equal to the geographic latitude of the location (+11°23′). This makes the telescope's axis parallel to the earth's rotation axis. Thus, a celestial source can be tracked continuously for 9.5 hours by a simple mechanical rotation of the antenna in the East-West

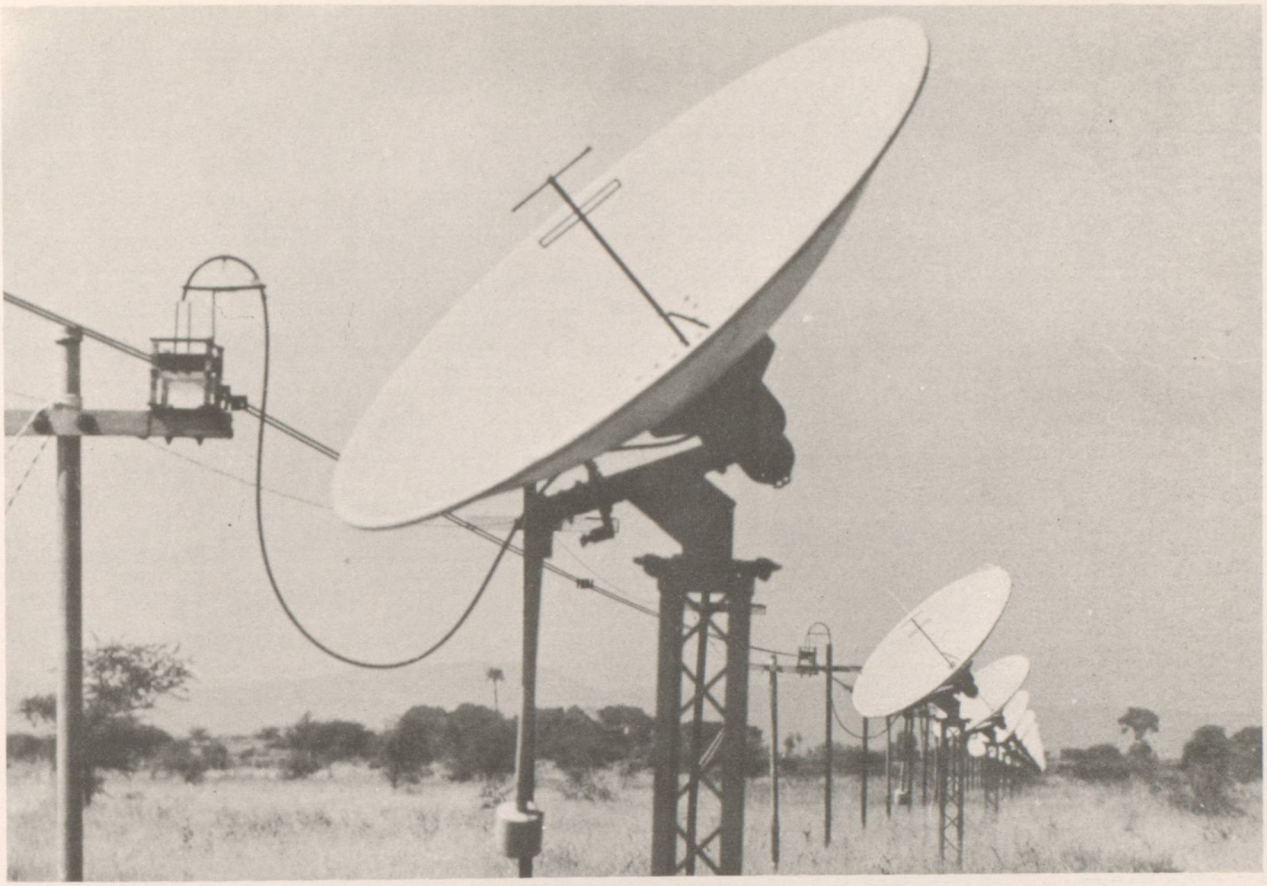


Fig. 2— The 32-element solar radio interferometer near Kalyan, Bombay.

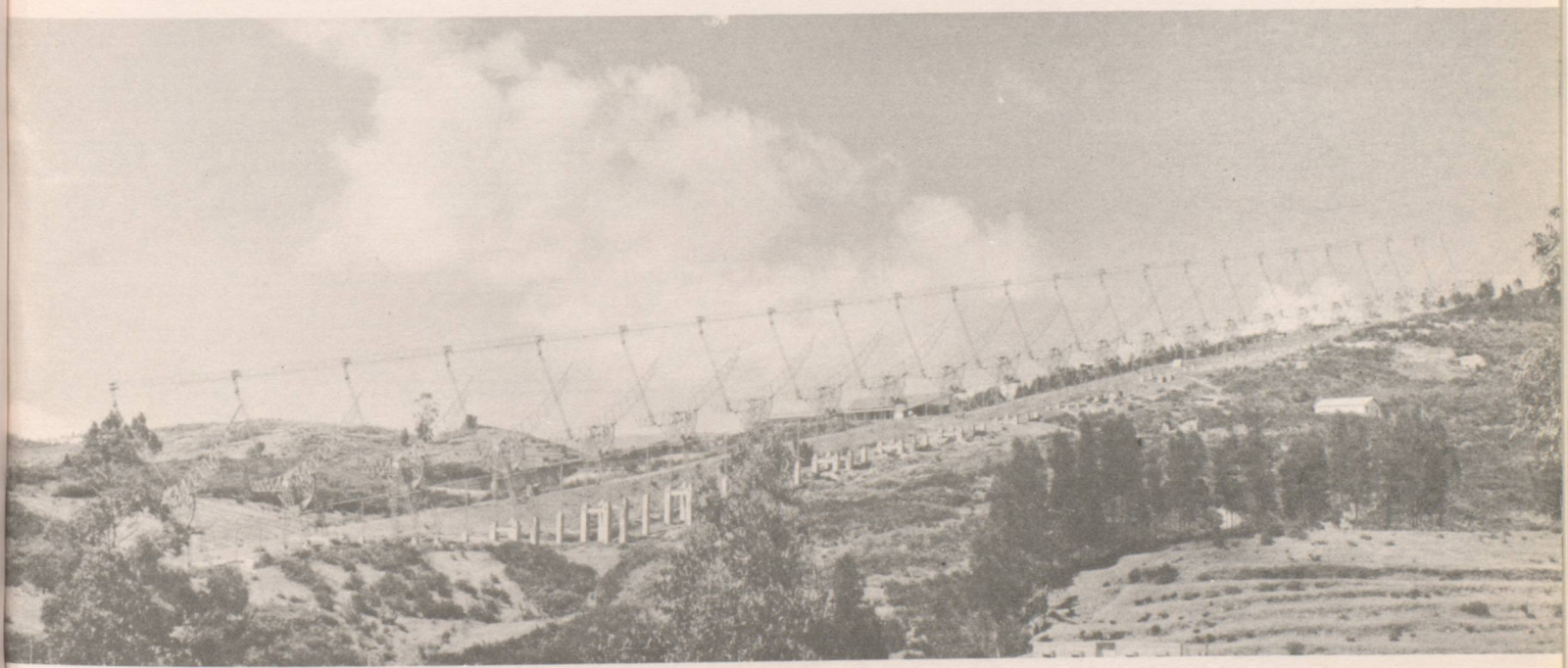


Fig. 3—The 530 m long Ooty radio telescope is located in a north-south direction on a hill of about 11° slope so that its axis of rotation becomes a parallel to that of the earth.

direction which compensates for the earth's rotation. In declination, the antenna beam is steered electrically, using a complex system of phase-shifters and delay lines. These connect a 968-element dipole array along the focal line of the parabolic cylinder to a central radio receiver system. The radio telescope was designed specially for lunar occultation observations of radio sources. But its ability to track a radio source with such a large collecting area makes it a very powerful instrument for many other types of investigations, specially those concerning weak radio sources. Moreover, its operating frequency of 327 MHz is well-suited for detecting the deuterium line from interstellar space, a vital observation for the studies of cosmic evolution. The Ooty radio telescope was conceived, designed and fabricated fully indigenously. The total cost of the project including buildings and other facilities was Rupees 5.8 million. In addition Tamilnadu Government provided the required land on a nominal lease. National Science Foundation, U.S.A. gave a grant of $70,000 for importing some essential components and an on-line computer system. The first observations were made in February 1970.

The operation of the Ooty radio telescope during 1970 led to a number of important results. The three major observational programs initiated in 1970 to be continued more intensively in later years, include:

(a) Studies of extragalactic and galactic radio sources by the method of lunar occultation.

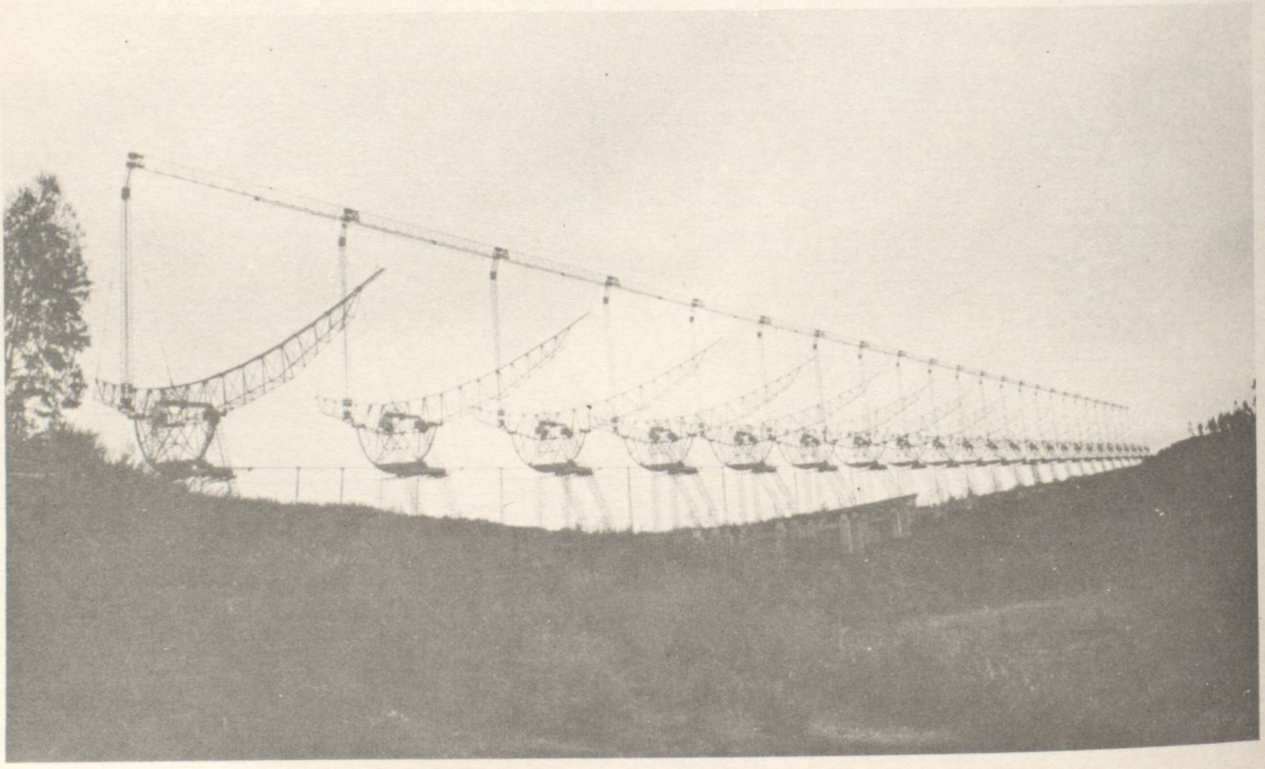


Fig. 4—A view of the 530 m long Ooty radio telescope which is located at an altitude of 2,200 meters in the Nilgiri Hills. Each of the 24 frames is 30 m wide. The telescope, shown pointing towards the zenith, can be rotated in unison by 140°.



Fig. 5—Another view of Ooty radio telescope which is amongst largest steerable radio telescopes in the world.



Fig. 6—A view of the control room. Signals received by the radio telescope are recorded on chart recorders and also on an on-line computer system.



Fig. 7—Part of the sophisticated receiver system which was built entirely at TIFR.



Fig. 8—Mr. J. R. D. Tata announcing the successful completion of the Ooty radio telescope in a press conference on April 2, 1970.

(b) Study of the interplanetary medium by observing scintillations of compact radio sources.

(c) Observations of weak pulsars and search for new pulsars.

The Lunar Occultation observations: The Ooty occultation observations during 1970 yielded accurate positions and angular structures with a resolution of a few seconds of arc at 327 MHz for over 100 extragalactic radio sources, most of which had been detected and catalogued for the first time. Such high resolution studies were hitherto confined mostly to centimetre wavelengths and to the sources in the 3rd Cambridge catalogue, which are almost an order of magnitude stronger compared to the sources in the above Ooty sample. The accurate positions and angular structures determined at Ooty for a large number of weak radio sources were utilised for identifying them with optical objects seen on the Sky Survey prints. The optical identification of strong as well as weak radio sources is clearly an important step towards understanding the intrinsic properties and cosmological evolution of different types of sources, such as quasars and radio galaxies.

The main idea behind measuring angular sizes of weak radio sources was to compare them with the known sizes of stronger 3C sources and thus evaluate the utility of angular size as a distance indicator for radio sources from the Ooty observations. The observations in 1970 indicated that the angular sizes of weak radio sources were statistically smaller than those of stronger sources, indicating that the former are located farther away. The above investigation was also aimed at determining the evolution of linear size of radio galaxies with cosmic epoch. The lunar occultation method is the most practical way for mapping both compact and extended components of radio sources with a high resolution

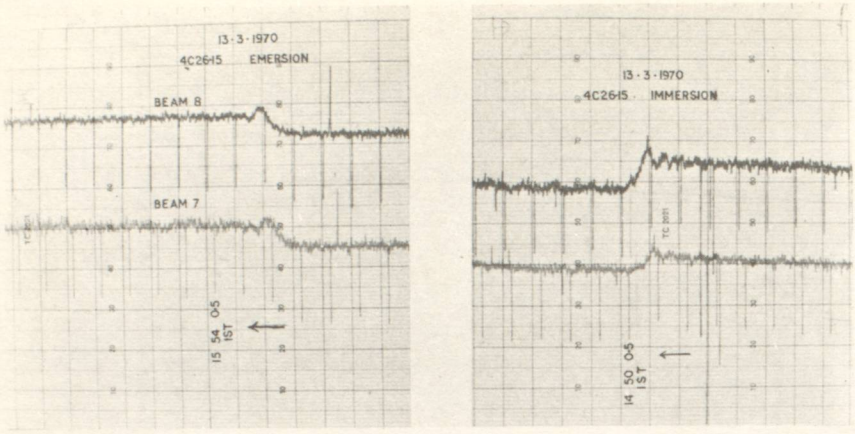


Fig. 9—A record of lunar occultation observations of the radio source 4C 22.21. Power received by the radio telescope increases as the source emerges from behind the moon's limb. The rate of increase (diffraction pattern) gives information about source structure.

at metre wavelengths, though at centimetre wavelengths such maps had been made using the aperture synthesis telescopes of a few km size at Caltech, Cambridge and Green Bank. A comparison of detailed structures of radio sources at centimetre and metre wavelengths has been a difficult but an urgent problem because of its importance to the theoretical models of radio sources dealing with the mechanism of supply of relativistic particles to different parts of radio galaxies and the question of leakage of relativistic particles from radio sources. The Ooty occultation program initiated in 1970 has led to several interesting results on all the above aspects of extragalactic radio sources and cosmology.

Among the galactic radio sources whose occultations are observed in 1970 is the radio source Sagittarius A which is of exceptional interest due to its coincidence with the centre of our Galaxy. The Ooty occultation observations provided the first evidence for a multicomponent configuration of this source at metre wavelengths — and for a nonthermal halo of size 20 parsec surrounding this galactic centre source. These results have contributed a great deal to our understanding of the complex region near the centre of our Galaxy.

Pulsar Observations: The second observational program at Ooty is focused on the fast-growing new area of pulsars, which are believed to be rotating neutron stars. Radio studies of these objects promise to yield new insight into the physics of highly condensed matter which is so dense that it is not possible to produce it in laboratories. The first aim is to survey the sky for weak and particularly short period pulsars. This required large data acquisition and computation because the field of view of the Ooty radio telescope is covered by not one but twelve beams. For this purpose, the development work was started for necessary hardware and software for use with the available computer and receiver systems. To start with, characteristics of the pulse emission from a few pulsars were determined.

Interplanetary Scintillation Observations (IPS): Rapid fluctuations in intensity of a radio source are observed as the radio waves from the source pass through the plasma irregularities of the solar wind. These observations provide estimates of angular sizes of compact components of less than 1 arc sec and also contain a great deal of information on solar wind itself. The IPS observations during

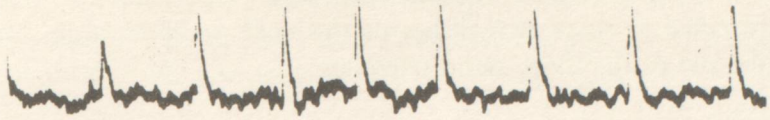


Fig. 10—A record of successive pulses observed at Ooty from the pulsar P.S.R. 1237 25 with a period 1.382448613 sec.

1970 were limited to a few selected sources which are known to be compact with an overall size of $\leq 0''.1$ arc. These observations were used for studying the scale size of irregularities in the interplanetary medium and its dependence on distance from the Sun.

The Ooty Aperture-Synthesis Interferometer

Work is started in 1970 for setting up a three-element interferometer, with the existing Ooty radio telescope as one of the elements, covering a baseline of about 4 kilometres. Installation of such an interferometer has been considered important since the Ooty radio telescope operating at 327 MHz has a large steerable area in the North-South direction and hence it could be used advantageously to construct a narrow beam interferometer for observing low-declination sources by adding several low-cost antennas. In the first stage, installation of two parabolic dishes of 13.7 m diameter was undertaken, along with



Fig. 11—The Supernova remnant, Crab Nebula, the explosion of which was seen by Chinese astronomers in the year 1054 A.D. A pulsar believed to be the rotating neutron star is located near the centre.

the development of a phase-stable microwave link for transmitting the signals received at these two dishes to the main receiver room located 4-km away at the site of the Ooty radio telescope.

Technological Fall-out from the Ooty Telescope Project

The vast experience gained during the construction of the Ooty radio telescope has contributed significantly to the design and construction of large microwave antennas needed for troposcatter and space communication within India. In 1968, the Radio Astronomy Group wrote a feasibility report for indigenous fabrication of the large 29 m (97-ft) antenna at Satellite Earth Station near Arvi. The responsibility for setting up this major earth station indigenously was undertaken by the Department of Atomic Energy with the participation of several organizations including TIFR and its successful completion within about 2½ years was a major milestone in space communications in India. In 1970 the Radio Astronomy Group undertook full responsibility for design and fabrication of several parabolic dishes of 4.5 and 13.5 m diameter for supplying to tropospheric research laboratories. The establishment of an antenna design group in the Department of Atomic Energy was initiated and suitable interaction was provided. This group was later transferred to Electronic Corporation of India Limited for taking up major antenna projects in the country.

THEORETICAL ASTROPHYSICS

This group was started in 1966 with the activities spread over a number of topics in theoretical astrophysics including Atmospheres of Cool Stars, Convection Zones in Stars, Models of Pulsars and the State of Matter at High Density.

With the discovery of pulsars in 1968 a good deal of effort was devoted to building theoretical models to account for the extreme regularity of pulsar periods and also to explain the emission mechanism. An attempt was made to interpret the radiation in terms of plasma oscillations originating in the magnetosphere of a neutron star. The fine-structure observed in the main pulse was attributed to repeated excitation of plasma waves. The linear polarization of the signals was supposed to be caused by the existence of a polarization limiting region in the star's outer magnetosphere.

Another model was suggested which examined the proposition that the qualitative features involved in the pulsar mechanism are similar to those responsible for a solar cycle. The solar cycle theory makes use of the observed differential rotation of the Sun, whose equatorial regions rotate faster than the higher latitudes. The initial poloidal field that connects the polar caps can be drawn out longitudinally by the differential rotation to form a much stronger toroidal field in the sub-surface layers. The conversion of the rotational energy into magnetic energy proceeds until a critical limit is reached, when an instability

sets in and the magnetic buoyancy then lifts the flux tubes to the surface to produce spot groups. This analogy of the solar cycle is utilized, by means of scaling, to explain the observed pulsar phenomenon.

The equation of state for cold matter has been studied by a number of workers to construct neutron star models and to obtain the upper limit of a stable neutron star. The extension of the calculations to densities higher than the nuclear density is faced with two principal difficulties:

(i) an inadequate knowledge of the nucleon-nucleon potential at higher energies, and (ii) the lack of reliable methods for computing the interaction energy of the system at densities exceeding the nuclear density. A solid-body model for dense neutron matter was proposed. This approach was based on the assumption that when the nuclear forces become sufficiently repulsive, a possible minimum energy state can be achieved by keeping the neutrons as far away from one another as possible, i.e. by localizing them at lattice sites. Such a solid lattice of neutrons in the core of the neutron star may be regarded as nuclear analogue of the Coulomb lattice of nuclei which exists in its crust. The lattice calculation was performed with the harmonic approximation using the classical Debye model and employing the Reid soft-core potential.

The evolutionary processes leading to the formation of collapsed objects were studied. The physical properties of white dwarfs, neutron stars and black holes were examined with special reference to their role in the context of pulsars and cosmic X-ray sources.

The speculation that the square of the electronic charge e^2 may have been increasing with cosmic time was examined. Arguments based on geochronological data were presented to show that a billion years ago the value of e^2 was the same as today, to within a few parts in ten thousand, assuming other constants are held invariant.

The theoretical study of late-type stars is important in many respects, although they are harder to study because of the various complications involved in problems of convection, molecular opacities, equation of state etc. Many studies were carried out with regard to the above problems.

In the equation of state, it is shown that it is important to consider all the important molecules formed out of the elements considered. Otherwise the electron pressure, thus obtained will be an upper limit. In the calculation of equilibrium constants one generally assumes that the partition function is a function of temperature only. However, at high densities, one has to consider pressure ionization or pressure dissociation as well.

The effect of interparticle interaction on the bound-free absorption coefficient of H^- under the Debye-Huckel approximation shifts the maximum of the coefficient as well as the threshold wavelength redward. This may be important in high density cool dwarfs.

In metal deficient stars, one finds that the main contribution of quasi-H_2 is in the ultraviolet region and is not important for $T < 3200^\circ$ K. The Rayleigh scattering contribution of He and heavier elements to opacity is very small in stars with solar elemental abundances. However, in carbon stars, specially in hydrogen deficient ones the contributions of some of these less abundant elements are shown to be quite important.

It is found that the density inversion occurs only in some of the models computed. Although it may be a real phenomena, the present evidence does not rule out its being due to inadequate treatment of the superadiabatic zone.

For the study of the nature of the interstellar grains, one has to know the scattering properties of spherical and non-spherical particles for electromagnetic radiation. As a potential model of interstellar grain, the problem of scattering of plane electromagnetic waves by infinite concentric homogeneous cylinders at oblique incidence has been worked out. Some results for extinction and polarization efficiencies for normal as well as oblique incidence have been computed.

The problem of scattering of X-rays from pulsar NP0532 by interstellar grains have been considered in detail. It is shown that the spectrum of the pulsed X-rays from NP0532 (in the 1-100 kev region) is affected only very slightly by scattering of interstellar grains. Consequently, the observed spectrum of the pulsed component in the 1-100 kev region should closely correspond to the spectrum of the pulsar at the source.

In the absorber theory of radiation, as formulated by Wheeler and Feynman, the radiation damping is worked out. The important feature of the derivation is that the absorber response on the radiating charged particle is calculated by incorporating the principle of action and reaction.

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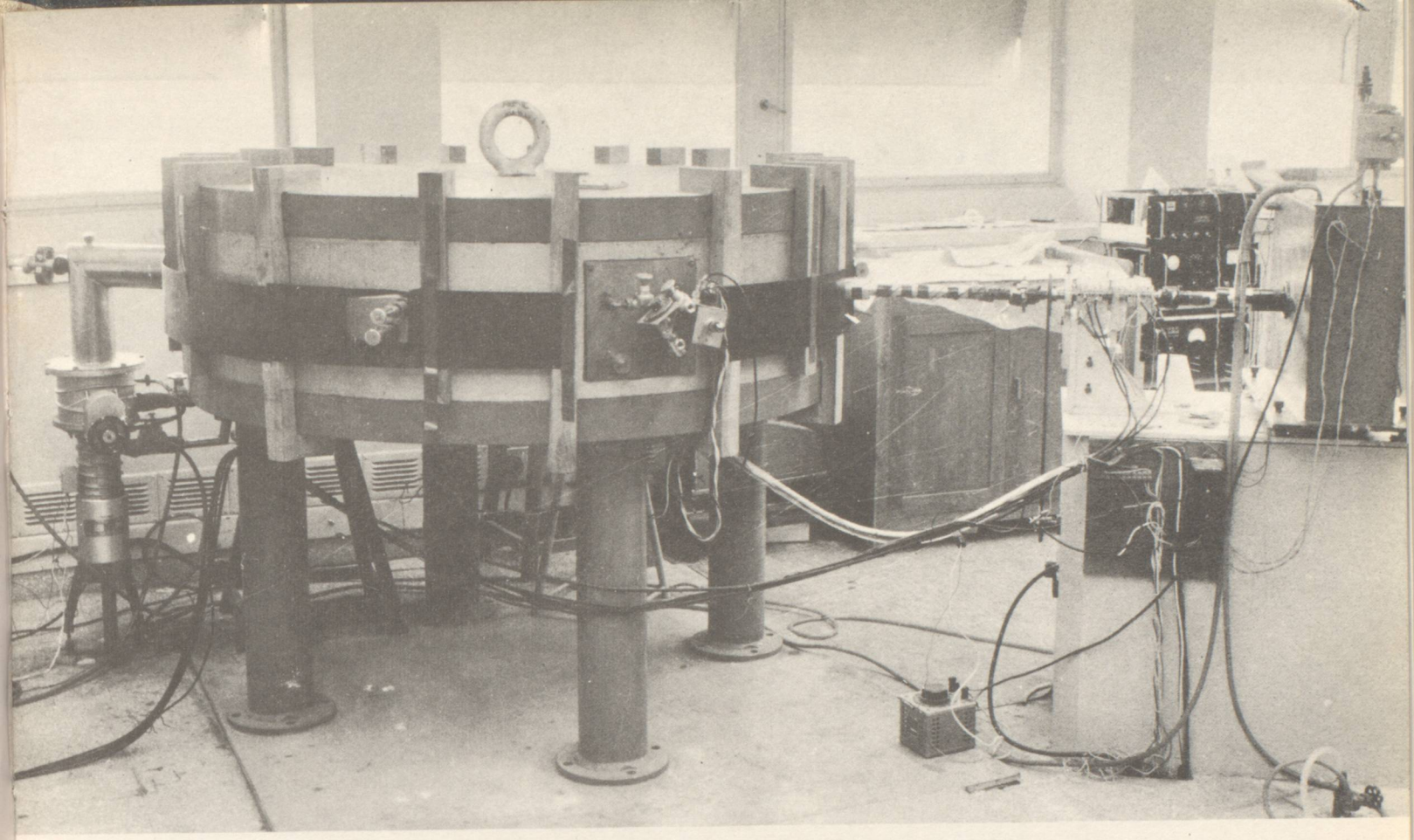
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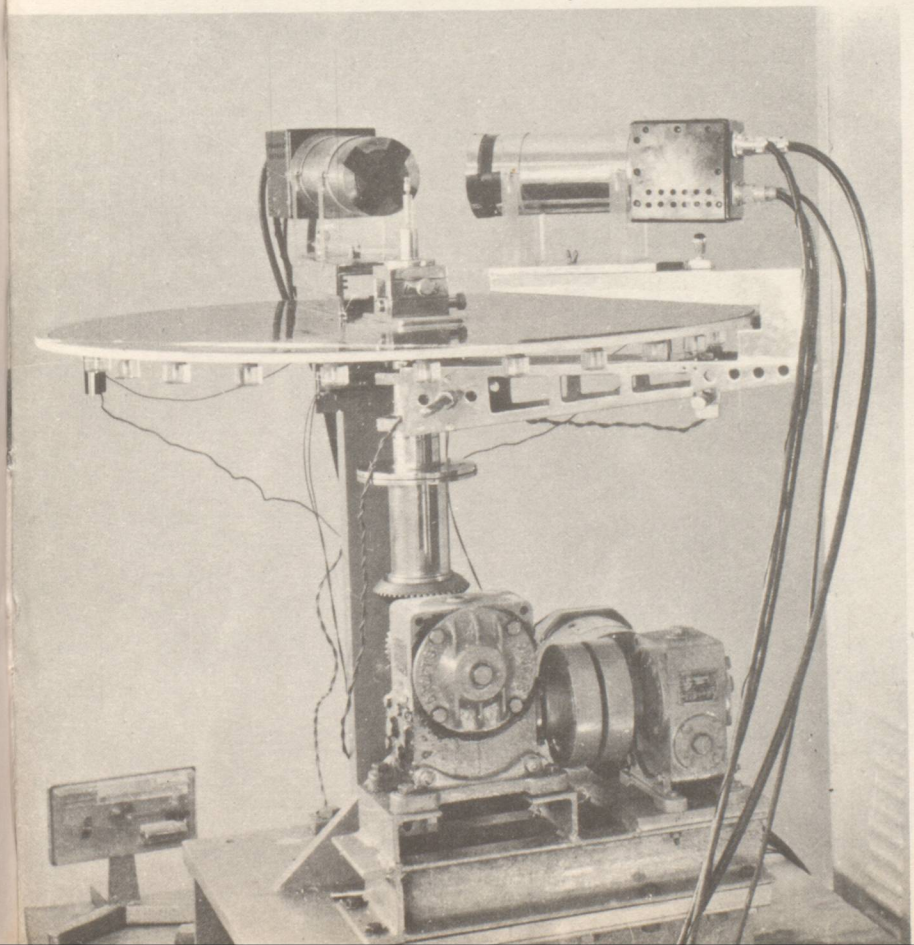
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NUCLEAR PHYSICS

NUCLEAR PHYSICS

Genesis

Research in nuclear physics was started in the Institute in the early 1950s and has, over the past two decades developed from very modest beginnings to a vigorous, purposeful activity. It may be recalled here that Dr. Bhabha, in his letter to the Sir Dorabji Tata Trust dated 12th March 1944, proposing the setting up of this Institute, had stated: "The subjects on which research and advanced teaching would be done would be theoretical physics, especially on fundamental problems, and with special reference to cosmic rays and nuclear physics. . . . ". He remarked further in this letter that the creation of such an institute and the carrying out of this type of research would have the benefit that: "when nuclear energy has been successfully applied for power production in say a couple of decades from now, India will not have to look abroad for its experts but will find them ready at hand". Indeed the Institute is today recognized as the "National Centre of the Government of India for Nuclear Science and Mathematics".

Early programmes

In the first phase of work in experimental nuclear physics, until about 1958, the principal activity was the acquisition and the construction of instruments and equipment needed for beta and gamma ray spectroscopic work, for neutron studies, for nuclear reaction studies and for the training of research and technical personnel in nuclear techniques. This was the period when nuclear reactors and accelerators, all over the world, had started producing a multitude of artificial radioactive isotopes, and there was intensive research activity aimed at understanding the structure of nuclei, through the study of radiations emitted by these. The use of accelerators to study the reactions induced in stable nuclei when bombarded

High resolution double focusing beta-ray spectro-meter: it is used to determine accurately Internal Conversion Coefficients and sub-shell ratios. The magnet was designed and fabricated at the Institute of Physics, Uppsala in Sweden.

Spectro-coincidence goniometer, designed and fabricated at the Institute, which is used for measuring the angular correlation of successive radiations. A number of beta-gamma angular correlation measurements using this goniometer have shown the validity of "selection rule effect" and "cancellation effect" in certain types of beta decays.

with energetic particles was another method of understanding nuclear structure. Various nuclear models had been proposed and were being tested by a detailed study of nuclear energy levels. And from the viewpoint of reactors and nuclear energy, there was need to carry out experiments on the diffusion and slowing down of neutrons in various media involving different configurations.

To carry out such studies, the main large items of equipment acquired were the one million volt Cockcroft-Walton high tension set installed in 1953; and the versatile Siegbahn-Slätis intermediate image beta-ray spectrometer commissioned in 1954. The commissioning of these instruments may be said to be the real beginning of a productive research effort in the area of experimental nuclear physics in the Institute.

The Cockcroft-Walton set has been used primarily as a neutron source. It has been employed extensively for a variety of programmes: for studies of the thermalization properties of moderating media and various lattice assemblies of interest in the atomic energy programmes; for irradiation of biological and other specimens for radiation damage studies; and for nuclear reaction studies. Very considerable technical modifications have been introduced to enlarge the scope of work with the Cockcroft-Walton set. This instrument will continue to be useful as a fast neutron irradiation facility; and a great deal of physics can still be done with it because of significant recent technical advances in the form of isotope separation techniques, large deuteron currents and new targets.

Nuclear Instrumentation

The Siegbahn-Slätis spectrometer was modified to a beta-gamma coincidence spectrometer by constructing a new pole-piece, and in this form it has been a powerful tool for work in nuclear spectroscopy. A thin magnetic lens beta-ray spectrometer was designed and constructed indigenously, mainly in the Institute

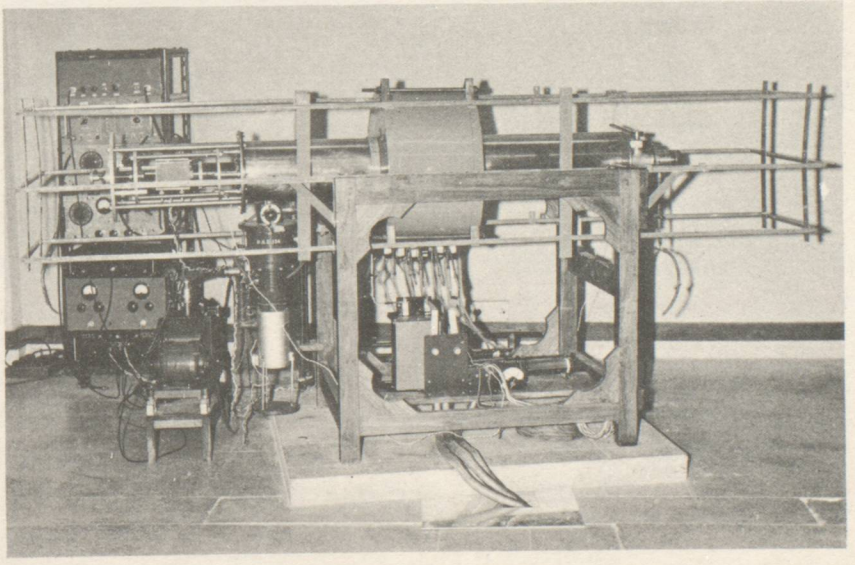


Fig. 1 — This Thin Magnetic Lens Beta-Ray Spectrometer, which was designed and fabricated in the Institute Workshop, has been used to study nuclear decay-schemes.

workshop. With the advent of scintillation spectrometry, considerable effort was directed towards the construction of coincidence and discriminator units and the setting up of experiments for the study of beta-gamma and gamma-gamma angular correlations. Among powerful and precision instruments constructed at the Institute for nuclear research the following may be particularly mentioned: (i) Compton polarimeter for measuring circular polarization of gamma rays; (ii) a single-gap high resolution magnetic beta-ray spectrometer; (iii) a six-gap magnetic spectrometer with 12% transmission; (iv) thin magnetic lens beta-ray spectrometer and (v) lithium-drifted germanium detectors for gamma-spectrometry. All of these were built indigenously. A high resolution magnetic spectrometer of Swedish manufacture and a 512-channel analyzer acquired around 1960, added significantly to the range and precision with which nuclear structure problems could be investigated.

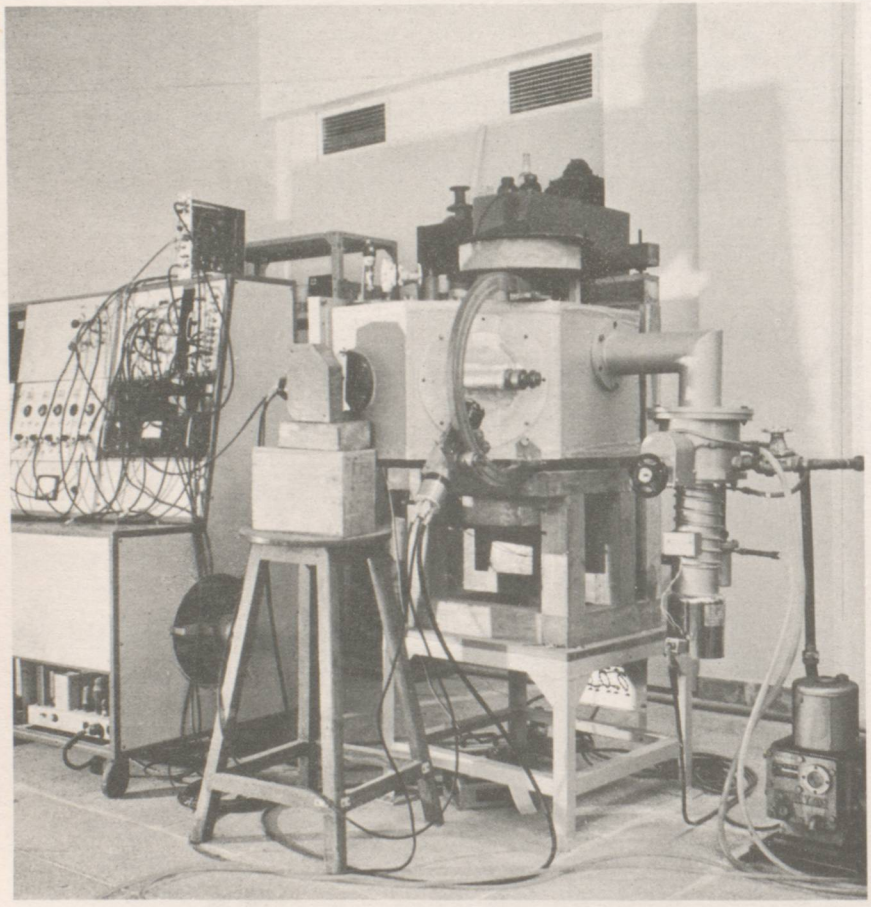


Fig. 2 — Single-gap beta-ray spectrometer: it is particularly useful for measuring conversion electron-gamma directional correlations. Such studies are directed towards measurements of the penetration matrix elements which are of importance in understanding nuclear structure.

Recent researches During the decade 1960-70, important work in the area of nuclear structure has been carried out. These studies have involved the investigation of the detailed properties of nuclear levels: energies, spins and parities, magnetic moments of excited nuclear states, beta-gamma-transition matrix elements, internal conversion coefficients and particle parameters.

During recent years, increasing use has been made of facilities at the Bhabha Atomic Research Centre (BARC), Trombay, for research in nuclear physics. Some equipment is placed on a continuing basis near the Apsara reactor, to study short-lived radio-active nuclei and processes following neutron capture and fission. The 5.5 MV Van de Graaff accelerator at Trombay has been used extensively for studies of nuclear reactions, Coulomb excitation of nuclear levels, and Mössbauer studies on nuclei embedded by implantation technique. A significant facility for nuclear research will be the Variable Energy AVF Cyclotron which is to be installed near Calcutta within a few years.

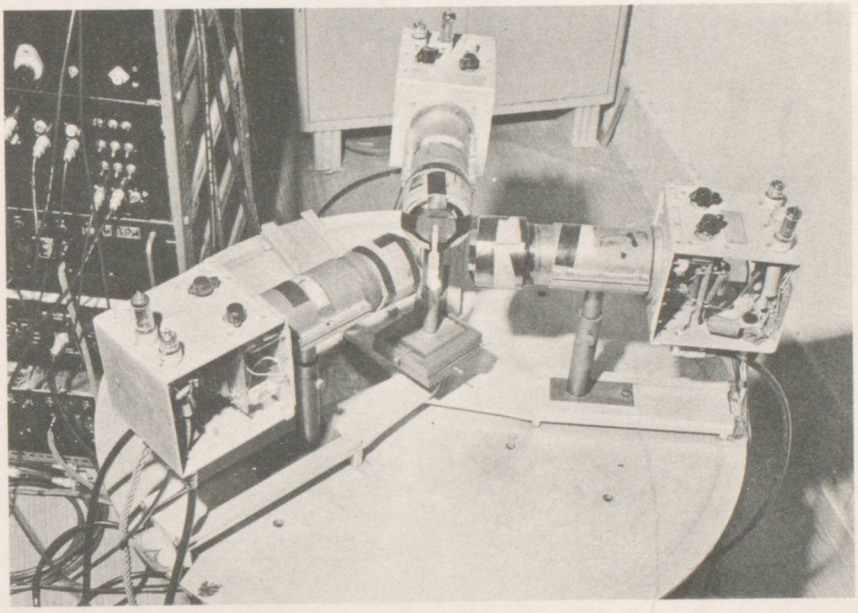


Fig. 3 — Three-detector coincidence set-up for angular correlation studies: it is used near the 1 MW Apsara reactor at BARC, Trombay, to study the energy levels of isotopes with short half-lives.

As a result of these programmes in the field of experimental nuclear physics, sophisticated nuclear techniques have been developed at the Institute that find wide application on the studies relating to solid state physics and material technology. In this respect, the Institute possesses a distinct advantage over other groups in the country, which follow the more conventional methods for such studies. In view of this aspect, the Institute has recently initiated programmes in the following areas: (i) Nuclear Orientation at low temperatures; (ii) Mössbauer studies; (iii) Positron annihilation studies; and (iv) Perturbed angular correlation of nuclear radiations.

Study of deformed nuclei and odd mass near-spherical nuclei:

Important research contributions

(i) There was a long-standing anomaly about the internal conversion coefficients for low energy gamma-rays in deformed, rare-earth nuclei. The coefficients as measured experimentally for these pure electric quadrupole transitions appeared to be 20 to 30% higher than the theoretical values. This was

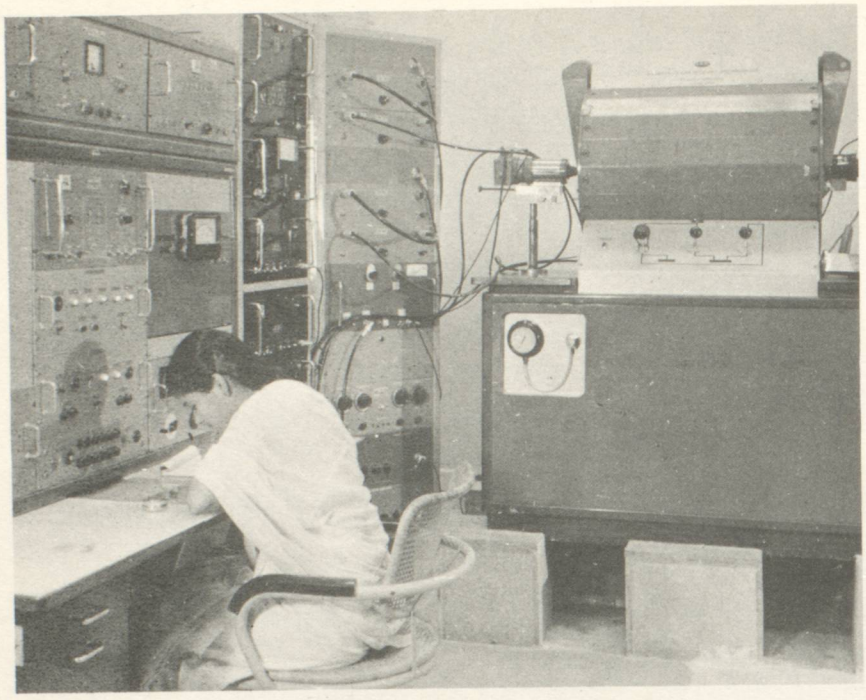


Fig. 4— This Intermediate Image Siegbahn-Slätis Beta-Ray Spectrometer of Swedish design and manufacture, has been used extensively in studies of the properties of nuclear levels. It was modified to give beta-gamma coincidence spectra and in this form is a powerful tool in nuclear spectroscopy.

puzzling to the theorists as no effect due to nuclear structure and finite size of nuclei, static or dynamic, was to be expected for these transitions. A systematic and careful series of experiments on these nuclei, carried out at the Institute, established that the previously reported values were in error and that there was in fact good agreement with theory. This finding has since been confirmed by different well-established groups in the world using various techniques. This has further been confirmed through measurements on particle parameters in these transitions in highly deformed nuclei, using a single-gap high resolution spectrometer, constructed at the Institute.

(ii) The unique position of the radio-active decay of Eu^{152} is well-known to all those engaged in research in nuclear physics. This is primarily due to the extensive work on this isotope carried out at the Institute, along with simultaneous work by many other groups all over the world. The electron-capture decay branch of Eu^{152} leads to the level structure of Sm^{152}, well described by a rotational model of a highly deformed nucleus Sm^{152}, whereas the beta decay mode of Eu^{152}, leads to the well-known vibrational spectrum of a spherical nucleus Gd^{152}. This is the sharp transition from a spherical shape at neutron number 88, to a well-known deformed nucleus at neutron number 90.

(iii) Extensive investigations on the energy levels of some of the odd mass near-spherical nuclei have been carried out. The level schemes of In^{117}, Au^{199}, Sb^{125} and $I^{127,\ 129,\ 131}$, were correctly established through these studies. It has been shown that the simple single particle or particle-phonon coupling picture is not adequate to explain the observed level schemes and that the states are largely affected by configuration mixing.

Magnetic moments of short-lived nuclear states:

Measurements on the magnetic moments of nuclear levels have provided significant information on nuclear structure. The results in Ta^{181} and Ca^{133} revealed substantial quenching of the spin magnetic moment of the nucleon in nuclear matter while in the case of I^{127} there is almost no quenching. The measurements in Pb^{211} established core-polarization effects on the odd nucleon moment. The studies of the phonon g-factors of vibrational states revealed that the microscopic structure of the one-phonon state is quite different from that of the two-phonon state. The measurement of the magnetic moment of the 660 KeV level in In^{117} is indicative of possible deformation in this excited state of the near-spherical nucleus. The magnetic moment of the 1829 KeV state of I^{131} shows that it is a neutron excitation level in this odd proton nucleus.

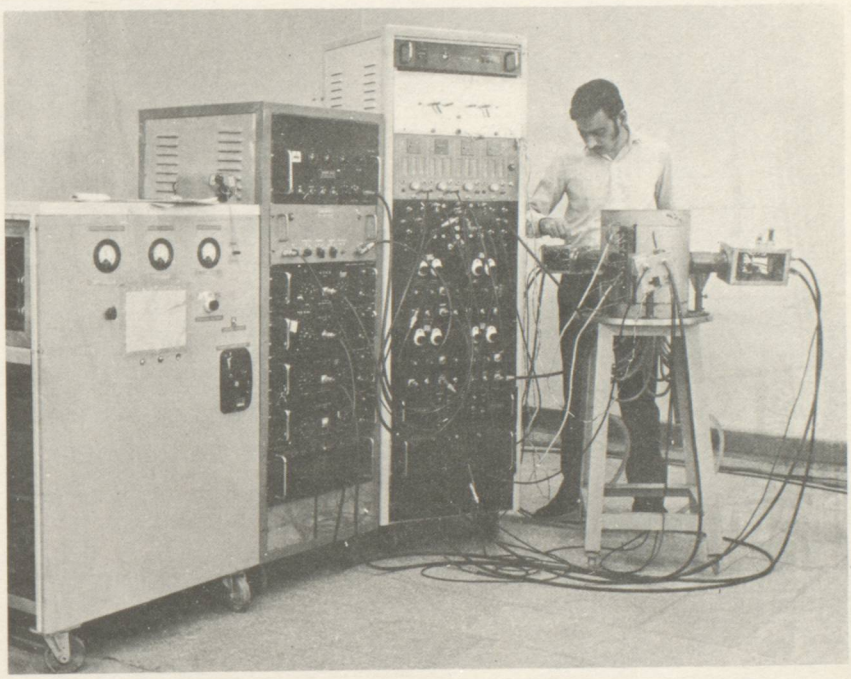


Fig. 5—Experimental set-up for measuring 'g' factors of excited nuclear levels by Perturbed Angular Correlation studies. Magnetic moments of excited states in several nuclei have been determined by this technique.

Magnetic moments of nuclear states with half-lives of the order of 10^{-11} sec. have been measured using internal magnetic fields acting on impurity nuclei in ferromagnetic lattices. Studies on magnetic moments of the levels in Te^{125}, Fe^{58}, Pt^{192} and Pt^{194} have been carried out in great detail using this technique. Use of Coulomb excitation with the 5.5 MV Van de Graaff accelerator at Trombay has been made to study states which may not be easily excited in radioactive decay. The inherent large anisotropy of the angular distribution of gamma radiation in Coulomb excitation has been used for perturbed angular correlation studies. This technique of perturbed angular correlations is also being used as a tool to study the hyperfine interactions. Mössbauer studies have been carried out to complement this information.

Parity violation and beta-decay matrix elements:

Immediately after the discovery of the non-conservation of parity in beta-decay and the subsequent experiments establishing the V-A character of the interaction, measurements of beta-decay matrix elements in some first forbidden transitions were carried out, that provided valuable information about nuclear structure. Eu^{152}, Eu^{154}, La^{140} and Ir^{192} were some of the isotopes studied by the method of beta-gamma angular correlation and beta-gamma circular polarization correlation.

The study of the shapes of beta-spectra of ^{147}Nd, ^{115}Cd and ^{186}Re revealed deviation from the statistical shape, indicating some cancellation effect on the matrix elements. Measurement of the longitudinal polarization of beta-electrons in Cd^{115m} with an electrostatic velocity analyser, using Mott scattering from a gold foil, showed deviation from the v/c law, supporting this conclusion.

Some measurements on the Fermi matrix elements in allowed beta-transitions were carried out, revealing vanishing Fermi moments, indicative of negligible isotopic spin impurities of the relevant nuclear states. This work has the important consequence that even in very heavy nuclei, isotopic spin may be a good quantum number.

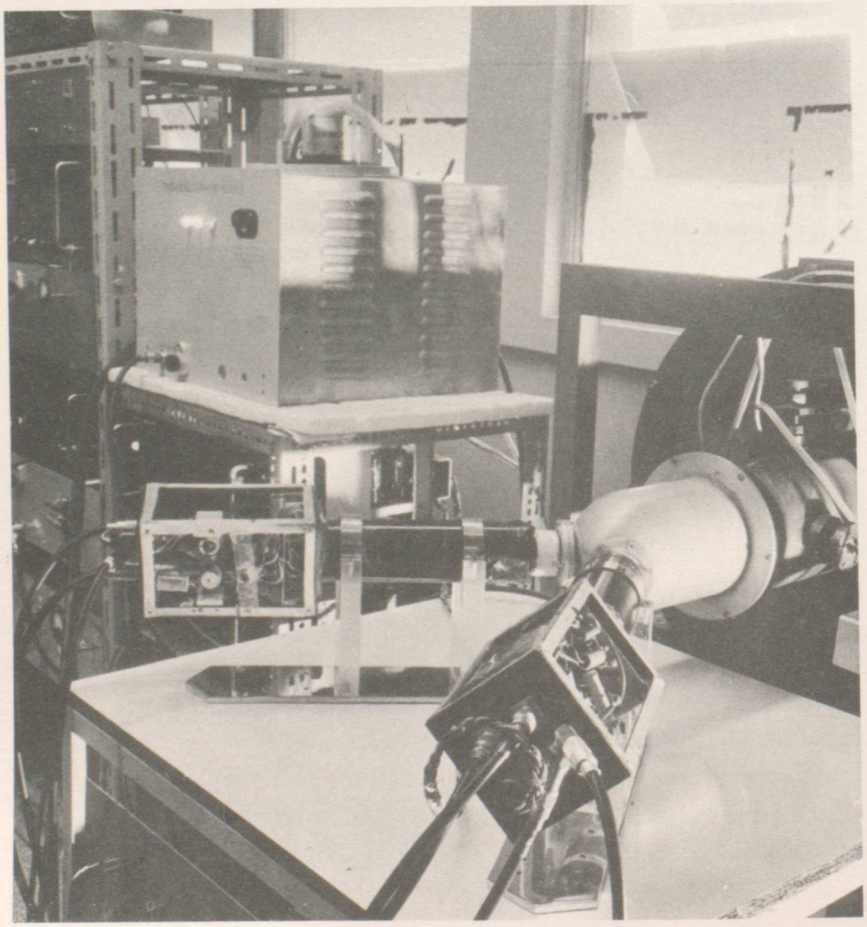


Fig. 6 — Experimental arrangement for measuring the longitudinal polarization of electrons and positrons using Moller and Bhabha scattering. A lens type beta-ray spectrometer is used as a monochromator to select electrons of definite momenta, which are then scattered by a thin magnetic foil. The outgoing electrons are detected by the two counters shown.



Fig. 7—Apparatus for measuring by Mott scattering the polarization of beta particles, using an electrostatic velocity selector. Deviations from v/c rule were observed for the first time in Promethium-147 and Cadmium-115m.

Neutron Physics and Nuclear Reactions:

Studies using the Cockcroft-Walton accelerator. The one million volt Cockcroft-Walton accelerator at the Institute has been in use primarily as a neutron source. Pulsed neutrons have been obtained with the Be^{9} (d,n) B^{10} reaction and a pulsed deuteron source. Diffusion constants and thermalization characteristics (i.e. the slowing down of neutrons to thermal energies) have been determined in the case of water and beryllium oxide as a function of size and temperature of the moderator. Measurements of the decay constants of beryllium oxide-natural uranium heterogeneous assemblies, as a function of the geometric buckling have also been made. These experiments were performed at the Institute as a part of the national reactor programme for which it is important to know about aspects such as prompt critical size, prompt critical multiplication constant, etc. for comparison with various theories.

The T(D,n) He^{4} reaction which yields mono-energetic neutrons in the energy region of 14 MeV, has been used for nuclear reaction studies. Using this 14 MeV netron source, several new cross-sections for (n,p), (n,d), (n,t) and (n,α) reactions have been determined. Interesting studies in the field of nuclear reaction

mechanism were undertaken at this energy, employing nuclear emulsions and gas proportional counter telescopes as detectors. Studies on the angular distribution of fission fragments in the fission of ^{235}U using the 14 MeV neutron source have also been carried out. Stripping reactions at low deuteron energies have been investigated; Coulomb field plays an important part in these reactions and spectroscopic factors could be determined from such stripping experiments.

Studies using the Van de Graaff accelerator: Using the 5.5 MeV Van de Graaff accelerator at Trombay, a number of nuclear reactions, viz. $C^{13}(d,n)O^{16}$, Cl^{37} $(p,n)Ca^{43}$ and F^{19} $(p,\alpha)O^{16}$ have been studied. In the case of the (p,n) reactions, the excitation functions of neutrons, and also of gamma rays following the emission of neutrons, the angular distribution of neutrons and also of gamma rays and angular correlations where possible, were measured; the objective was to obtain information on the spin and parity of nuclear levels of interest and concerning the interaction mechanism responsible for the reaction. It was established that the random phase approximation was not valid for the compound nuclei ^{38}Ar and ^{52}Cr formed in the reaction $^{37}Cl + p$ and $^{51}V + p$ respectively, at the excitation energies reached in these studies; on the other hand, it was found to be valid for the compound nucleus ^{56}Fe formed in the reaction $^{55}Mn + p$. The study of the excitation functions of α_0 and α_{1+2} groups in the reaction $^{19}F(p,\alpha)$ ^{16}O in the proton energy range 2 to 3.6 MeV, revealed a few wide structures in addition to a large number of narrow structures typical of compound nuclear resonances.

The measurement of x-ray yields produced by the K shell ionisation and Coulomb excitation of deformed nuclei by the bombardment of α—particles has formed another set of important experiments carried out at the Van de Graaff machine. The x-ray yields due to K-ionisation in Sn, Te, Ce, ^{144}Sm, ^{152}Sm, ^{154}Sm, ^{160}Gd, ^{186}W, and Pb by energetic α—particles have been accurately measured. The comparison of the observed yields in ^{144}Sm which has a spherical nucleus with those in ^{152}Sm and ^{154}Sm which have deformed nuclei has conclusively shown that there is no excess of x-ray yields in deformed even-even nuclei as indicated earlier in the literature and attributed to higher internal conversion in these cases. These measurements have further proved that the K-shell conversion coefficients of pure E2 transitions in deformed nuclei remain unaffected by nuclear deformation.

The Van-de-Graaff machine is also used for the study of the energy levels of odd mass isotopes of Rh, Ag and In by inelastic scattering of protons. This facility at Trombay is also utilized for carrying out Perturbed Angular Correlation studies following Coulomb excitation.

Neutron irradiation studies: Several varieties of seeds and animals were irradiated with fast neutrons from the Cascade Generator from time to time and these were studied for radiation effects by various laboratories, viz. (i) Indian Agricultural Research Institute, Pusa, Delhi; (ii) Radiation Genetics Laboratory, Osmania University, Hyderabad; and (iii) Biology and Medical Division, BARC.

Plans for research during the 1970's

It is planned to continue nuclear structure studies on important, selected problems using existing equipment at the Institute and the facilities available at BARC, Trombay; and to develop as an effective user group for nuclear work with the Variable Energy (AVF) Cyclotron near Calcutta, when this machine becomes operational in the near future; with regard to the latter programme, groups engaged in research in experimental nuclear physics at the Institute are working on the development of experimental facilities to be used in conjunction with this Cyclotron, such as (i) the fast neutron facility, (ii) a 30-inch scattering chamber and (iii) the fabrication of Ge(Li) detectors for charged particles.

The high-transmission six-gap magnetic beta-ray spectrometer will be installed in the thermal column of the 1 MW Apsara Reactor at Trombay, for conversion electron spectroscopic studies on nuclei, following neutron capture.

An extensive programme of work has been planned for the use of the pneumatic withdrawal or "Rabbit" facility at the 40 MW CIRUS reactor, where short-lived radio-activities with half-lives of the order of a few minutes can be studied.

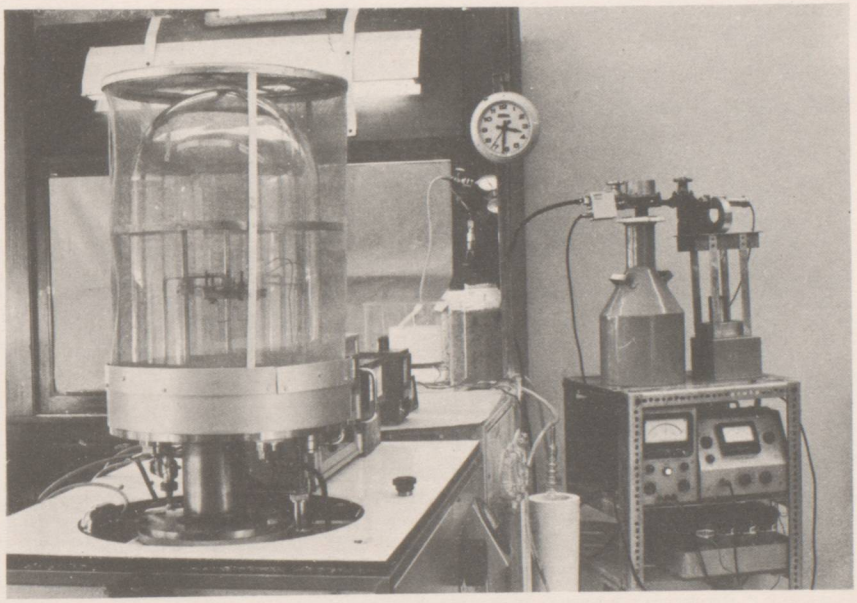


Fig. 8—A view of the laboratory for the fabrication of lithium-drifted germanium detectors which are widely used today for high resolution gamma spectroscopy. Planar type germanium detectors have been made for the first time in India in this laboratory. Detectors with depletion thicknesses upto 8 mm have so far been made.

Research effort in areas common to solid state and nuclear physics is to be strengthened; additional to programmes in this category that are already in hand, it is planned to start work on implantation techniques with charged particles at the Cascade (TIFR) and Van de Graaff (BARC) accelerators; and also to take up work, relating to the newly discovered 'string effect', arising from the channelling of charged particles through single crystals.

It is also proposed to use a high resolution iron-free, beta-ray spectrometer for photo-electron spectroscopy as a tool for the investigation of some chemical structure problems, viz. shifts in electron binding energies with different chemical environments of the atom.

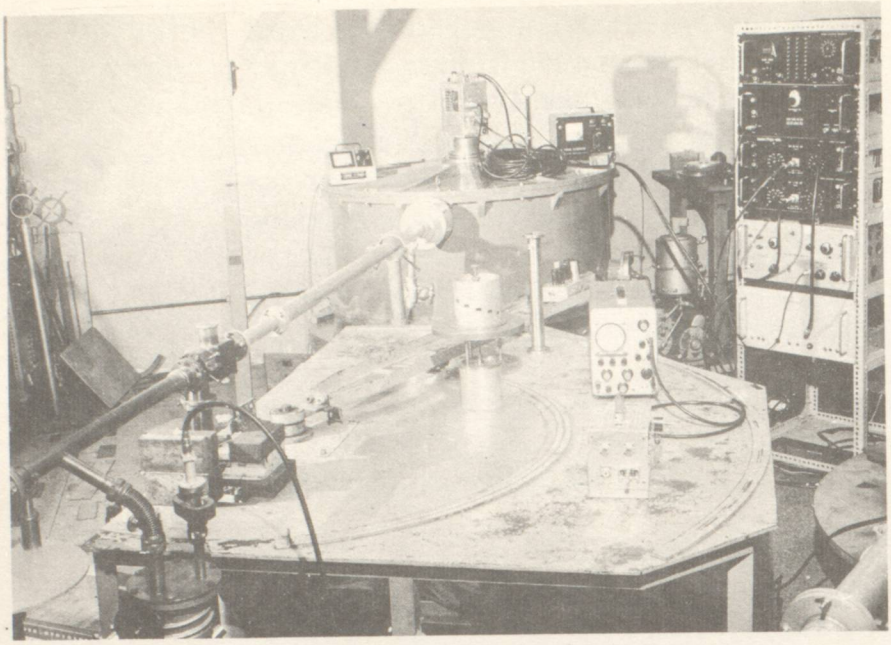


Fig. 9 — Six-gap 'ORANGE' betaray spectrometer, of the Copenhagen type, fabricated in the Institute; it is presently being used with the 5 MV Van de Graaff accelerator at BARC, Trombay. The spectrometer has already been used for studies of various isobaric analogue states. It will be used at the APSARA reactor for studying internal conversion electrons following thermal neutron capture and later for nuclear reaction studies with the AVF cyclotron being set up at Calcutta.

The 1 MeV Cockcroft-Walton Accelerator

The one million-volt Cockcroft-Walton accelerator (Cascade Generator) was installed in the Institute in 1953. This accelerator has been used extensively by scientists from the Institute and from the BARC, Trombay, as well as scientists from various other scientific institutions in the country. Its principal uses have been as a pulsed neutron source to study the thermalization and diffusion properties of moderators and multiplying media, as a source of mono-ergic fast neutrons to investigate nuclear reactions, and as a fast neutron source to study radiation effects on biological and chemical samples.

This Cascade Generator accelerates protons and deuterons upto a maximum energy of one million volts; recently singly charged alpha particles have been accelerated in this machine; it will soon be used to accelerate He^3 ions. It was originally supplied by Phillips, (Eindhoven), with an ion-gauge type of ion source; this was replaced by an r-f ion source constructed in this laboratory in 1954; an analysing magnet (permanent magnet) is used to analyse the ion beam before it impinges on the target.

The accelerator was originally installed in a shed at the site where the Institute is now located; in 1953 this site was covered with hutments and sheds which had to be used for the research work of the Institute before the permanent buildings were put up. The Cascade Generator was shifted in 1960 to its present location in a high hall at the southern end of the Institute building.

An additional column operating on the same high voltage unit, but in parallel with the main column, and at half the maximum voltage of the main accelerator, was added in 1963 to enable two independent experiments to be conducted without interfering with each other. This indigenously assembled accelerator

together with proto-type high voltage condensers and rectifier units, constructed from locally available components for making a 500 KV high voltage generator, was given to Andhra University, Waltair, in 1967 to start nuclear reaction work there.

The first paper describing an experiment carried out with this accelerator was published in 1955; this was on the energy levels of Fe^{56} and Al^{27} by the inelastic scattering of 15 MeV neutrons produced through the T(d,n) reaction.

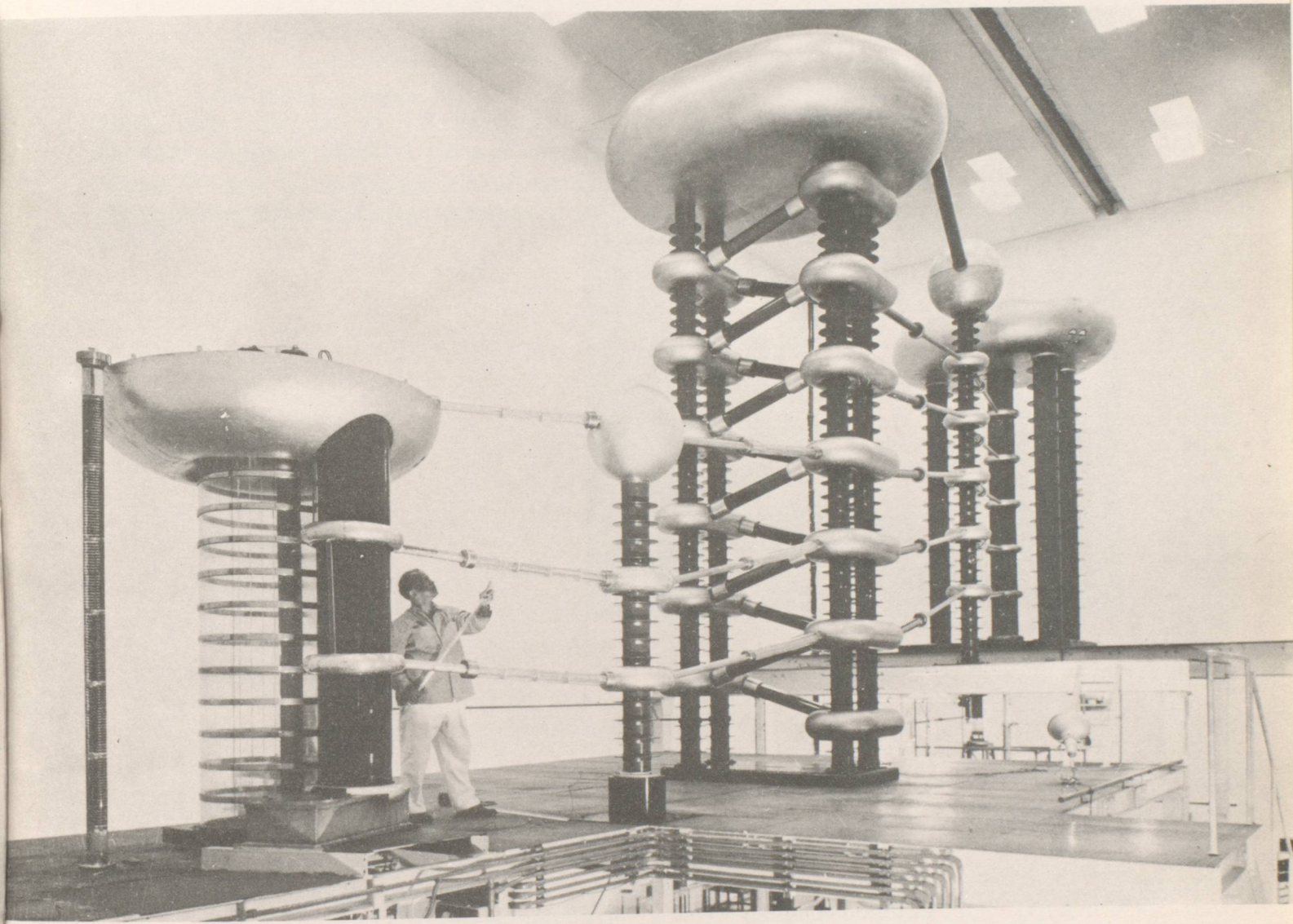


Fig. 10—The Cascade Generator, installed in 1953, has been used extensively for studying a variety of nuclear reactions as well as for studying the slowing down and diffusion of neutrons in different moderator assemblies. This accelerator can produce beams upto an energy of 1 MeV and currents upto 200 micro-amperes. It has recently been equipped with beam analyzer systems made in the Institute for studying charged particle reactions at low energies.

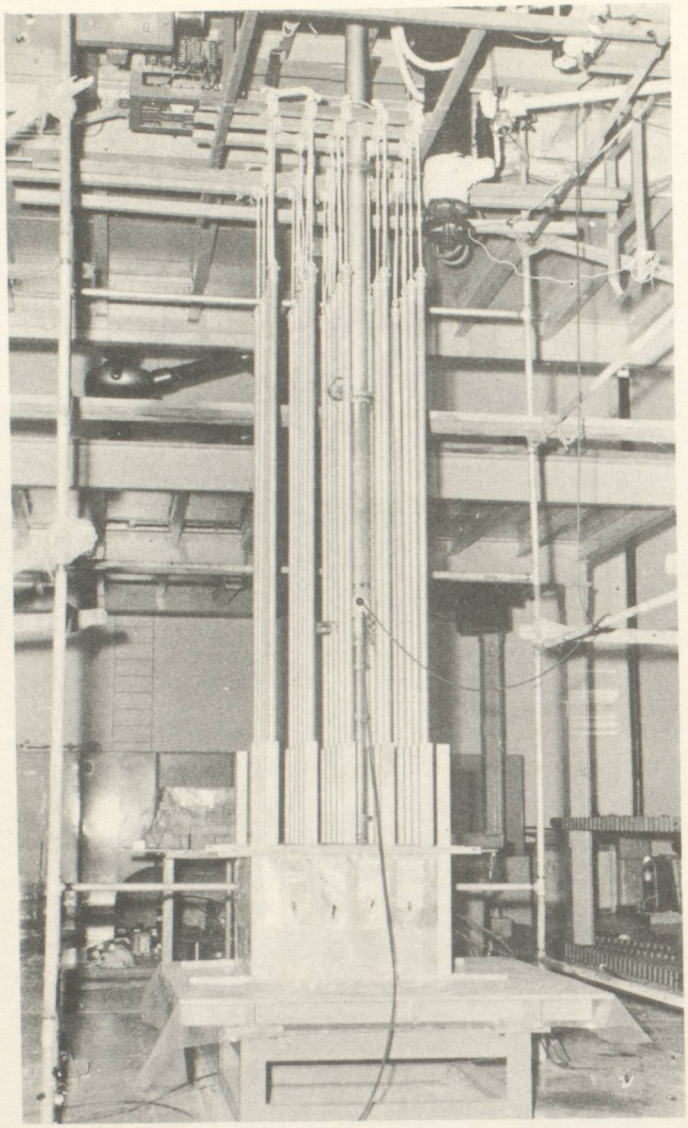


Fig. 11 — View of an experimental set-up at the Cascade Generator for studying the neutron distribution in a multiplying medium of uranium rods and beryllium oxide bricks. This experiment was carried out in collaboration with the French Atomic Energy Commission, in order to investigate the properties of beryllium oxide as a moderator.

In 1955, the r-f ion source was pulsed to give pulses with a width of 30 microseconds and a repetition frequency of 600 pulses per second. This pulsed source was used to determine the diffusion and slowing down constants in water and Beryllium oxide; in 1957 the temperature dependence of the slowing down and diffusion constants were measured using this accelerator.

Simultaneously, the accelerator was used as a source of mono-ergic fast neutrons, generated through the D(d,n) and T(d,n) reactions; these neutrons were used to study a variety of fast neutron induced reactions: (n,n), (n,p), (n,d), (n,α), and (n, fission). Scintillation crystals, gas proportional counter telescopes and nuclear emulsions were employed for these studies. Angular distribution experiments in low energy stripping reactions like B^{11} (d,p) B^{12}, have been carried out. The accelerator has been used as a source of mono-ergic

gamma rays generated through the reactions Li (p,γ) and F^{19} (p,$\alpha\ \gamma$); these gamma rays have been used for studying photonuclear reactions like Bi (γ,p). Nuclear emulsions loaded with natural Uranium have been employed to study the emission of alpha-particles in the fission process at a neutron energy of 14 MeV. A large number of 14 MeV neutron cross-section for (n,2n), (n,p), (n,α), (n,d) and (n,t) reactions have been measured and reported. These experiments have resulted in significant contributions towards the understanding of the nuclear reaction mechanisms of the compound nucleus and direct interaction type, and the fast neutron induced fission process. About forty papers have been published so far by groups from this Institute and BARC based on the use of this accelerator.

The Indian Agricultural Research Institute, Pusa, Delhi, the Radiation Genetics Laboratory, Osmania University, Hyderabad and various divisions of BARC such as the Biology and Medical Division, the Health Physics Division, the Radio-chemistry Division, etc. and several universities in this country have extensively used this accelerator as a radiation source of fast neutrons and carried out studies on radiation damage in biological and chemical samples.

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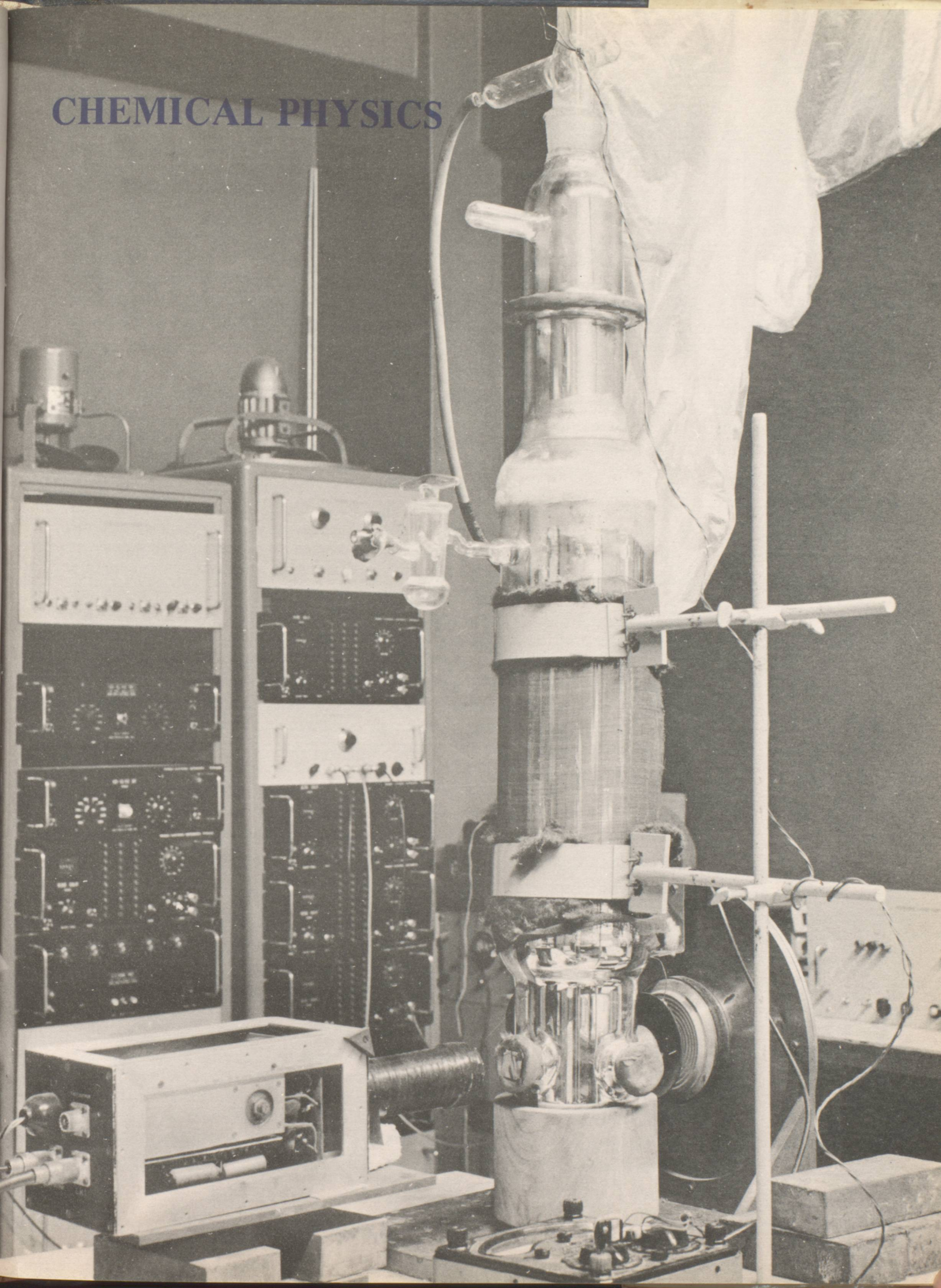
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CHEMICAL PHYSICS



CHEMICAL PHYSICS

General remarks

If a chemist can understand how the properties of a compound arise, he can very often modify the compound or synthesize a similar new compound so that he has a substance related to the first, but which possesses modifed properties that answer a specific need. It is well known that the clue to understanding the physical and chemical properties of a compound lies in its chemical structure, by which we mean the geometrical arrangement of the atoms that go to make the compound and the nature of the bonds that hold the atoms together. Further, the study of the several steps involved in a chemical reaction in which a particular compound participates (or is produced) can be related to the structure of that compound and will lead to suggestions to modify the steps to synthesize a new compound. Such exercises in research are applicable also to biologically important compounds, whether they be part of the biological system or things that react with biological systems. There are several methods available to tackle such problems and in TIFR we have chosen a few of the recently available elegant methods, most of which are magneto-chemical. The emphasis in the work of the group in the earlier years was on magnetic resonance and magnetic susceptibility but more recently it has been enlarged to cover Mössbauer studies, Microwave Spectroscopy and Cyclic Voltammetry combined with photochemical work.

The Nuclear and Electron Magnetism Group: its genesis and historical development

In 1953, when the late Prof. S. S. Dharmatti joined TIFR, after his brilliant research with Prof. Felix Bloch on what can be said to be the foundations of High Resolution NMR (nuclear magnetic resonance), he straightaway concentrated on the task of building up of a Group, the Nuclear and Electron Magnetism Group, devoted to Magnetic Resonance. His earlier work on magnetic susceptibility at the (then Royal) Institute of Science, Bombay, helped him to develop an interdisciplinary programme in which both physicists and chemists were involved in putting

A Mössbauer Spectrometer designed and fabricated at the Institute for chemical investigations. The picture shows an experiment at liquid helium temperature. The equipment, which is being used for the study of intermetallic compounds of tin and coordination compounds of iron, can be operated automatically and can also be coupled to a multichannel analyser.

to use the recently discovered phenomenon of Magnetic Resonance. At an early stage we developed our own NMR spectrometer using a cheap Swiss Magnet. It was a very successful venture and the experience gained enabled the group to exploit fully the High Resolution NMR and wide line NMR spectrometers which were imported later in 1957. The importing of these spectrometers did not stop the group from building up its own equipment and by 1965 the group had fabricated a wide line NMR spectrometer, a spin-echo NMR spectrometer, an ESR Superheterodyne Spectrometer, a Pure Quadrupolar Resonance Spectrometer, a Microwave Spectrometer for gases and a Magnetic Susceptibility apparatus; also the temperatures at which studies could be undertaken were extended, for most of the instruments to cover a range from 4.2°K to 500°K. A Mossbauer spectrometer fabricated in BARC also found a place in the group in 1963 for studies of chemical interest for which this spectrometer was appropriately modified.

Chemical Physics

In 1967, the Nuclear and Electron Magnetism Group was divided into two parts: that part which was mostly concerned with investigations on solid state joined similarly oriented groups in the Institute to form the Solid State Physics Group; the remaining part of the NEM Group was mostly concerned with chemical studies and is now being developed as a Chemical Physics Group. The main aim of the Chemical Physics Group is to undertake research in areas of chemical physics which are currently of great importance and interest. With this in view, we have slowly increased our activities in theoretical chemistry and also initiated programmes in Electrochemiluminescence. We hope to build in turn a viable chemical physics group working in the frontier fields of structural and theoretical chemistry. The emphasis in the group has very much been on building most of the equipment required for research; and with this training it has been possible to provide high level personnel for research and development activities to the Indian Institute of Technology, Powai, to the Microwave Engineering Group, TIFR, to the Molecular Biology Group, TIFR and to the Bhabha Atomic Research Centre. The group has also throughout made available the research and training facilities at the Institute, to universities and other research institutes in the country, in the areas of magneto-chemistry, nuclear and electron magnetism, etc.

The present activities of the Chemical Physics Group can be divided into the following broad areas:

Magnetic Susceptibility
Magnetic Resonance
Mössbauer Effect
Electrochemiluminescence
Microwave Spectroscopy
and Theoretical Chemistry.

We shall attempt here to explain the basic principles of these methods and then illustrate with examples chosen from research carried out at this Institute how

these have been applied to resolve problems in chemistry. We shall also attempt to bring out significant contributions made by this group; for a complete coverage of all the contributions the list of publications appended at the end should be consulted.

Magnetic Susceptibility

The major contribution to the magnetism of materials arises from the fact that electrons behave as tiny magnets because of their orbital and spin motions. In most chemical compounds, the electrons are paired off, either in their lower energy levels or with electrons of other atoms in the process of formation of chemical bonds, leaving the compound with no net magnetic character or magnetic moment as it is called. Such substances are said to be "Diamagnetic" and the majority of compounds fall in this category. However, if the molecular system contains unpaired electrons, as it happens in compounds containing transition metal ions or in free radicals which may be formed by the rupture of a chemical bond, then the molecules exhibit properties similar to that of a small magnet. These tiny molecular magnets may be randomly oriented because of thermal motion so that the system as a whole may not behave as a magnet; such materials are said to be "Paramagnetic". If, however, there are internal interactions which tend to orient the individual molecular magnets in any preferred direction we may have a "Ferromagnet". Under different circumstances, this interaction can lead to "Antiferromagnets" and "Ferrimagnets".

Since diamagnetic substances do not possess any net magnetic moment, the effect of an external magnetic field is to induce a magnetic moment opposite in sense to the applied magnetic field; and if the magnetic field is not uniform over the sample there will be a net repulsive force on the sample due to the interaction between the induced magnetic field and the non-uniform magnetic field. Paramagnetic molecules, in contrast, will tend to align with the magnetic field to minimize the energy of the inherently magnetic molecules, and a non-uniform field over the sample will exert a force in a direction opposite to that in the case of a diamagnetic sample; the strength of the force will also be orders of magnitude larger than that felt by a diamagnetic sample. The study of these forces lead to the estimation of a parameter called the "Magnetic Susceptibility", which can be correlated with the electronic structure of the molecule, and this information can be linked with bonding and structural details of the molecule.

Measurements on magnetic susceptibility can be carried out with a sensitive balance which can measure the force felt by the sample in an inhomogeneous magnetic field. Such a balance called Gouy Balance, has been set up and used extensively in the Institute, involving measurements down to about 80°K. Measurements of this type have been carried out on several cobalt complexes, rare-earth salts, metals and alloys. These studies can be coupled with other studies on the samples, using optical, magnetic resonance and Mössbauer spectroscopic techniques. For example, it has been shown here that a study of the temperature-independent-paramagnetism in several spin-paired cobalt (III) and Fe (II) compounds can give information regarding the strengths of the ligand fields. The measurement of mag-

netic susceptibility of intermetallic compounds of the rare earths with platinum has thrown light on the exchange interaction between the conduction electron spin and the rare earth spin. The magnetic susceptibility data of U(IV) and Ce(III) compounds have been utilized to get information regarding the effects of the electric field of the surroundings, (crystal field effects); on the energy levels of the paramagneticion. Some new compounds of nickel halides with dimethyl sulphoxide and pyridine-N-oxide have been isolated and their structure established from the magnetic susceptibility data and absorption spectra in the visible region.

Magnetic Resonance

While magnetic susceptibility measures the bulk behaviour of samples in a magnetic field, resonance techniques study spectroscopic transitions between electronic levels which are responsible for the susceptibility behaviour. However, one should add here that it is not only electrons that possess magnetic moments; certain nuclei of atoms also possess an inherent magnetic moment. This property of nuclei was discovered in the early part of the twentieth century as a result of studies on the hyperfine structure observed in the electronic spectra of atoms and molecules. The magnetic moment of a proton is about seven hundred times smaller than that of an electron, and most other nuclei have still smaller magnetic moments. The effect of such a small magnetic moment cannot be detected with bulk measurements of magnetic susceptibility unless one uses extremely sensitive

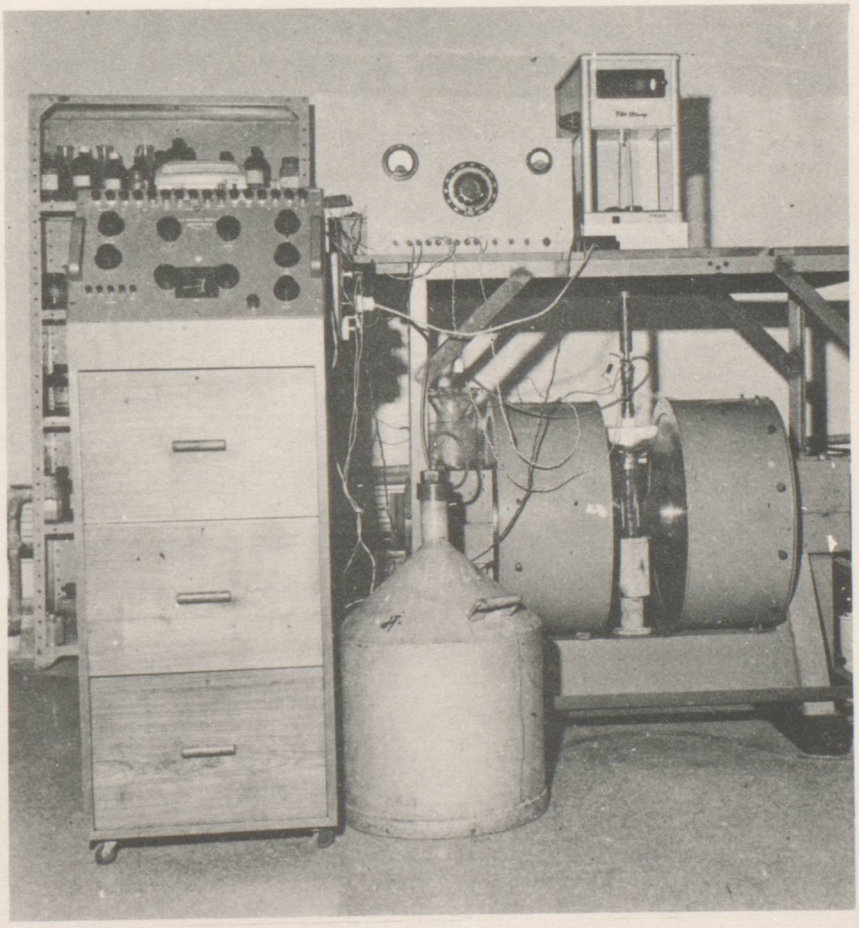


Fig. 1—A Gouy balance for the measurement of magnetic susceptibilities between 80°K and 400°K. The equipment including the magnet was fabricated at the Institute. It is used for the study of transition metal complexes and intermetallic compounds.

techniques. However, the discovery of magnetic resonance, which followed closely the development of atomic and molecular beam resonance techniques, opened up a new method for studying the magnetic properties of nuclei and electrons by spectroscopic techniques; the applications of these methods in chemistry and solid state physics have established them as very important tools for research in these areas.

For understanding the principles of magnetic resonance, one can consider a free electron or nucleus as a tiny magnet, which when placed in a magnetic field tends to align itself to minimize its energy. However, quantum mechanics allows only certain possible values for the components of the magnetic moment along the magnetic field axis and these are described by the allowed m_S (or m_I) values if the electron (or nucleus) has a spin angular momentum S(or I). Immediately, one recognizes that m_S (m_I) describes different energy states for the free electron (or nuclei) in the magnetic field. It is the spectroscopic transitions between these energy levels caused by an oscillating magnetic field that is described as electron (or nuclear) magnetic resonance. A look at the magnitude of the energy level separations involved will give an insight into the type of interactions we are looking at. In a magnetic field of about 3400 gauss, the separation between the two energy levels of a free electron ($m_S = ½$ & $m_S = -½$ corresponding to $S = ½$) is of the order of 4×10^{-5} eV or about 0.9 cals/mole; a transition between these levels would emit or absorb electromagnetic radiation of frequency 9500 MHz (about 3 cm wave length), which lies in the microwave (RADAR) range. For a proton with $I = ½$, the transition between the $m_I = ½$ and $m_I = -½$ levels is about 14 MHz (in the radio frequency region) for the same magnetic field. In the presence of an oscillating magnetic field of the right frequency to observe resonance, it is well known that the probability for electrons (or nuclei) to jump from a lower level to a higher level is the same as the probability to jump from a higher level to a lower level. Hence, there will be no net absorption of power from the radiation unless there is a net excess of electrons (or nuclei) in the lower level; the distribution of population between the two states is governed by the Boltzmann equilibrium and in the case of protons at room temperature and in a field of 3000 gauss there is a population of one million and six in the lower state as compared to a population of a million in the higher state. The situation is better in the case of electrons. The energy of the quantum involved in the transition and the negligible population difference between the lower and the higher states immediately emphasize the importance of great sensitivity in the detecting systems needed for observing magnetic resonance. And it is no wonder that the discovery of resonance was delayed until the end of World War II when great advances in electronics were made.

Since the separation between the energy levels depends on the strength of the large steady magnetic field, the frequency of resonance absorption will be a function of the magnetic field. It is clear that it is not only the external magnetic field that the nucleus or electron sees but also magnetic fields due to its immediate neighbours, viz. other electrons and nuclei. It is the study of these local magnetic fields which change the frequency, shape and structure of the resonance curve that has made Magnetic Resonance so useful in the studies of both static and dynamic effects in chemical physics and solid state physics.

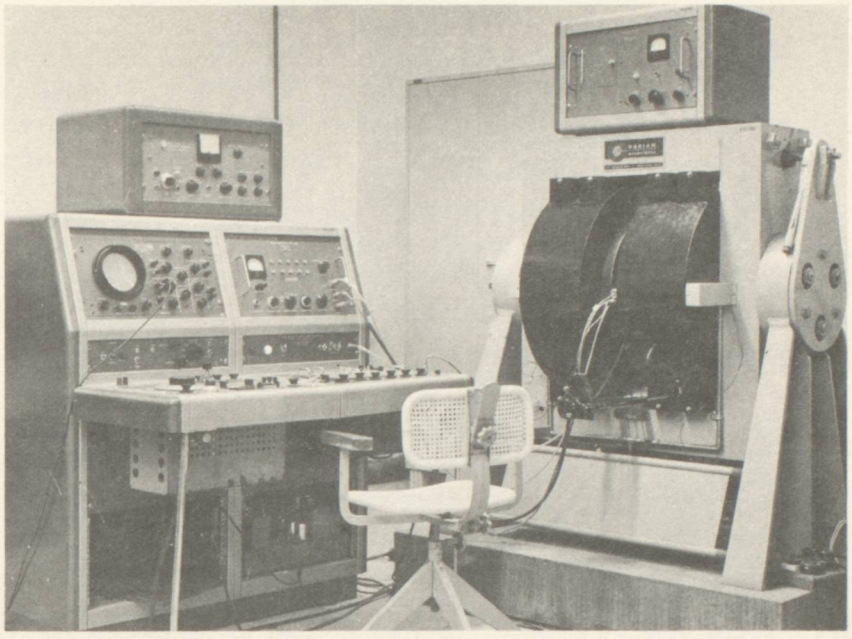


Fig. 2—A Varian High Resolution NMR Spectrometer working at 60 MHz. This equipment has been extensively used for studies of the structure of organic and inorganic compounds. The present interests of the group are directed towards transition metal complexes, biological molecules and molecules oriented in nematic phase.

The Chemical Physics Group is equipped with a Varian 60 MHz High Resolution NMR Spectrometer for studying proton and fluorine nuclear magnetic resonance; the temperature of measurement can be varied from about 170°K to 500°K. An additional 10 MHz RF unit offers facilities for study of some nuclei other than ^{1}H and ^{19}F (e.g. ^{31}P, ^{13}C). For electron spin resonance or ESR (the term used for magnetic resonance involving electrons) there is a partly imported and partly home-built X-band ESR Spectrometer with 100 KHz magnetic field modulation. An X-band ESR Superheterodyne Spectrometer has been built at the Institute which can be used for both relaxation and resonance work. For relaxation work, which will be described later, the spectrometer is pulsed with a microwave switch capable of nano second operations. The two ESR Spectrometers can operate from 4.2°K to 500°K. In the next two sections, on High Resolution NMR and on ESR are described some of the important results have been obtained at the Institute which illustrate the principles just mentioned.

High resolution NMR

The proton of a molecule feels, besides the external magnetic field, the magnetic fields due to neighbouring electrons and nuclei. In a diamagnetic compound like ethyl alcohol, the protons present in each of the three different groups (CH_3, CH_2 and OH) have different electronic environments; this is reflected in resonance measurements made under good resolution conditions, in which the magnetic field and radiating frequency are very uniform and constant. Then, it is observed that the three different groups of protons resonate at different frequencies; besides, each group shows a further structure which arises from the

fact that each group of protons experiences the magnetic field due to the other groups of protons. The first effect is referred to as "chemical shift" and the second as "spin-spin coupling" in NMR terminology. Since the study of chemical shifts and spin-spin coupling involve techniques that require a high resolving power of the spectrometer, this field of study has come to be known as high resolution NMR.

In TIFR, the early experiments on high resolution NMR were mostly concerned with the study of hydrogen bonding and analysis of complex spectra, particularly in cases in which the chemical shift and the spin-spin couplings were of the same magnitude. This required calculations of the energies of the various nuclear spin states, and solving the secular equation using computer methods and fitting the observed spectra with the theoretical calculation. From the spectra of di-substituted benzenes, the effect of the substituents on the two parameters was studied. It was found that the shift has a simple relation to the distribution of electron densities at the various proton sites. The results also showed a correlation between the steric effect of the substituent and the spin-spin coupling constants.

Considerable work has been done at the Institute on the effect of solvent-solute interactions on the chemical shifts and coupling constants. As a result of this work, a new method was proposed for the estimation of aromaticity of organic compounds and for the study of molecular association in aromatic compounds.

Recently, work has been started on the NMR of organic molecules oriented in liquid crystal media. Analyses of the spectra of such oriented molecules provide information regarding the geometry of the molecule as also concerning the anisotropy of the chemical shift and spin coupling parameters and the absolute sign of the indirect coupling in these compounds. This is at present a frontier area and it is planned to carry out more NMR work on this in the future.

Another area of active NMR study has been concerned with coordination compounds. Use has been made of Co resonance, observed with the help of a wide line NMR spectrometer, to study several cobalt compounds. The large chemical shifts observed in these compounds are highly sensitive to the nature of the ligands attached to cobalt; the magnitude of the shifts have been correlated with the strength of the interaction between the metal and the ligand (ligand field strength). Problems dealing with cis-trans isomerism and hindered rotation have also been investigated. More recently, work has been undertaken on NMR of paramagnetic compounds. In these compounds the interaction of the unpaired electron with the nucleus results in an additional, much larger shift called the contact shift, the magnitude of which depends on the spin density of the unpaired electron at the nuclear site. The observed contact shifts have been used for the estimation of thermodynamic parameters for the complexes under investigation and to get an idea of delocalisation of the unpaired spin to the ligand.

The chemical shifts of ^{17}O in liquids have shown that it is possible to identify from the shift values the type of bonding in organic compounds. The quadruple coupling constants of ^{11}B observed in borates indicate that boron exists in tetrahedral and trigonal coordination in tetraborates.

Electron spin resonance

As in the case of NMR, study of electron spin resonance (ESR) leads to an understanding of the magnetic interactions of the electron and its surroundings. It is obvious that one cannot have in matter a free electron in the strict sense; and all the features of the ESR spectrum describe the extent to which the electron is not free. For example, the electron could have an orbital angular momentum, besides its spin, which can contribute to the magnetic moment of the electron. It could interact with other electrons and magnetic nuclei of the molecule. It is such an interaction (termed hyperfine interaction) between the electron of the hydrogen atom and the magnetic moment of the proton of the hydrogen atom that gives rise to the 21 cm line so important in radioastronomy.

In the case of transition metal ions, the energy levels of the free ion are considerably modified when it is placed in a crystal where it is surrounded by groups; the extent of modification is decided by the symmetry of the arrangement of the groups and the nature of the groups. The ESR of such an ion immediately throws light on the symmetry of the arrangement and on the strength of the interaction between the groups and the central ion. For example, study of the ESR of Cr^{5+} in $CaWO^4$ at the Institute showed that the Cr^{5+} ion occupies the substitutional site of W in the crystal. Similar studies have been made here on Eu^{2+} in KCl, Eu^{2+} in CdF^2 etc.

When a crystal is exposed to highly energetic radiation like X-rays, electrons or gamma-rays, the crystal gets damaged and often paramagnetic centres are created which can be identified, and their site-symmetry determined by ESR. In irradiated single crystals of Cesium Uranyl Nitrate it has been possible to show here the formation of the NO_3 radical; and in o & p-toluidinium bromide, the formation of cyclohexadienyl type of radicals has been established.

In free radicals formed in chemical reactions considerable information about the electronic structure is available from a study of the hyperfine interaction, (i.e. magnetic interaction between the electronic magnetic moment and the nuclear magnetic moment) as discussed earlier. It is possible to test valence theories like Huckel Molecular Orbital Theory and its refinements by comparing their predictions with the hyperfine structure from free radicals. Usually the hyperfine structure is from protons in aromatic systems but it is also possible to have structure arising from ^{14}N, ^{13}C, ^{31}P, etc. At this Institute many labelled aromatic compounds have been synthesized from $BaCO_3$ containing enrichment of ^{13}C to 50% (natural abundance is 1.1%) and their ESR spectra studied to test valence theories of aromatic free radicals. It should be pointed out here that the naturally preponderant ^{12}C nucleus does not have a magnetic moment. When radical ions are formed they can interact with other ions of opposite charge and such ion-ion interactions have also been investigated by ESR. Besides, in many reactions the intermediate steps involve free radicals which when identified lead to an understanding of the reaction mechanisms. Several similar studies have been carried out to aid other chemists in the country.

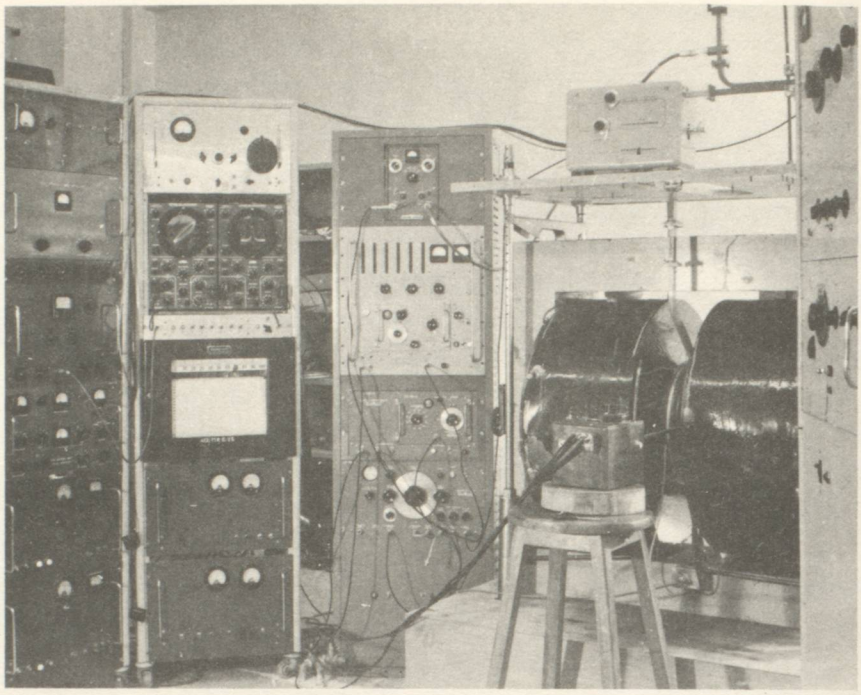


Fig. 3—An X-Band Electron Spin Resonance Spectrometer with 100 KHz modulation. Parts of the spectrometer, including the magnet power supply, were designed and fabricated locally. The magnet made from indigenous Tata A grade steel is at present located with its power supply in the Physics Department of the Indian Institute of Technology, Powai. This spectrometer has been utilized for Ion-pairing studies in free radicals, and ^{13}C hyperfine measurements in free radicals, besides other interesting photochemical and kinetic studies.

Spin lattice relaxation

It was mentioned earlier that the observation of magnetic resonance depends on the small excess of electrons or nuclei in the ground state over that in the higher states. However, when the system is perturbed by intense electromagnetic radiation causing transitions, this equilibrium may be disturbed; and on removal of the perturbation, the system will tend to come to thermal equilibrium. The rate at which it reaches equilibrium depends upon the interaction it has with its surroundings (referred to as the lattice); such studies which determine the rate of equilibration are called spin-lattice relaxation studies. The study of spin lattice relaxations throws light on the dynamic interactions felt by the electrons or nuclei and is a very useful technique in both NMR and ESR. The superheterodyne ESR spectrometer fabricated in the Institute can be pulsed to study relaxation effects that last longer than 3 micro sec. Such studies have been carried out in other laboratories on transition metal ions but such studies on free radicals were performed for the first time at this Institute.

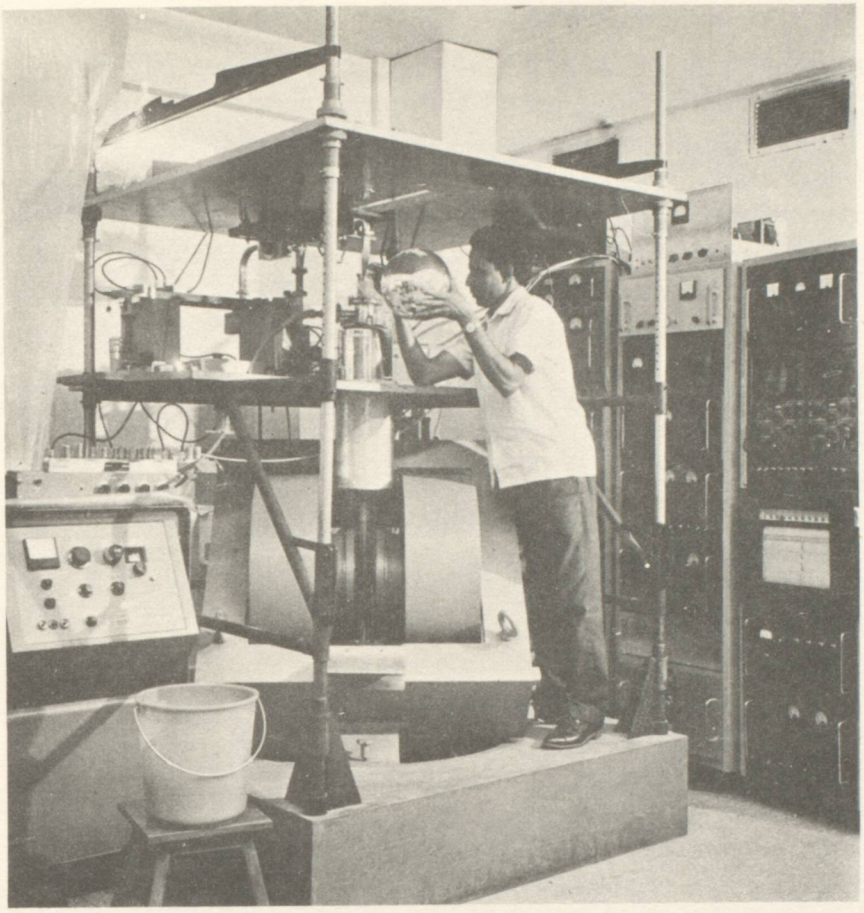


Fig. 4—An X-Band Electron Spin Resonance Superheterodyne Spectrometer with a rotating Varian Magnet, which has been designed and assembled at the Institute. It can be pulsed and is available for resonance and relaxation measurements. It is used for measurements of spin-lattice relaxation times in the micro-second region of organic free radicals and anisotropic studies in the solid state.

Mössbauer Spectroscopy

Mössbauer Spectroscopy is a new analytical technique based on the phenomenon of recoil-less emission and absorption of gamma-rays by nuclei bound in solids. The gamma ray resulting from the decay of an excited nucleus is used to excite, resonantly, the same state in an identical nucleus. This has been feasible because of the possibility of obtaining, under certain recoil-free conditions, very narrow gamma-ray lines, with fractional line-widths of 10^{-13} which means an accuracy of one part in 10^{13} in the determination of nuclear energies. The resolution thus achieved in a Mössbauer Spectrum is intrinsically higher than in any other branch of spectroscopy. Consequently, it is possible to study with this method, the variations in the nuclear energy levels brought about by the hyperfine interactions the nuclei have with their surrounding electrons. It is thus the influence of the chemical environment on the gamma-ray transitions that constitutes the basis for the application of the Mössbauer effect in studies of chemical bonding. Chemists having realized the potential of this new technique have used

it extensively for studies of chemical bonding, crystal structures, electron density, ionic states and magnetic and other properties. It is now considered a complementary tool to NMR, NQR and ESR.

Work on Mössbauer effect in TIFR started towards the end of 1963 with a view to study iron and tin compounds and alloys. Two pieces of equipment using electromechanical drives were built here. One of these drives works at constant velocity whilst the other works at constant acceleration. Spectra can be obtained at various temperatures between 4°K and 700°K.

The group has studied a number of platinum-tin and rare-earth-tin-intermetallic compounds. The spectra of Pt-Sn compounds show correlation with the Knight shift data obtained by the Solid State Physics Group here and provides information regarding the band structure of these alloys. The work on rare earth tin alloys throws light on the polarisation of conduction electrons by the rare earth spins. Work has also been carried out on Pd_2MnSn which is a ferromagnetic alloy below 180°K; in this case the results provide information regarding the magnitude and the sign of the internal magnetic field acting at the tin site. The origin of the field can be explained satisfactorily as being due to spin density oscillations arising from the scattering of the conduction electrons by the unpaired spins on the Manganese atom.

Electrochemiluminescence

Interest at this Institute in electrochemiluminescence has been on one particular aspect, namely, the emission of energy as visible light when positive or negative ions, or both, are created near an electrode by electrolytic techniques. Com-



Fig. 5—Electro-chemiluminescence: The emission spectrometer (on the right) scans the spectrum (200 nM to 800 nM) during electrolysis with alternating potential or at constant direct current. This system, fabricated at the Institute can also record emission from photo-excited molecules. The excited states of heterocyclics have been investigated with these techniques and electron spin resonance.

pounds that exhibit this property are very few, but the phenomenon is of great importance from the viewpoint of the pure as well as the applied chemist. A cyclic voltametric module, a photoelectric system with monochromators and the ESR spectrometers are all being employed for a detailed study of this phenomenon. For instance, it has been possible to establish here the sequence of reactions that lead to emission of light when a solution of 5-cyanoindole is electrolysed with a direct current.

Microwave Spectroscopy

The energy of an isolated molecule can be separated into electronic, vibrational and rotational contributions. The electronic motion gives rise to spectra in the visible and ultraviolet range; the vibrational motion of the atoms produces infrared spectra; and the rotational motion of the molecule gives rise to absorption in the microwave region in the wavelength range of 3 cm to 3 mm, which is the range of RADAR operations. Microwave spectrometers are employed to observe such spectra.

To a first approximation a molecule may be treated as a rigid body which rotates freely in space, but whose rotational speeds have definite values. The jump, (or transition as it is called), from one rotational speed to another involves a change in energy which is equivalent to a quantum of microwave radiation. Since the rotational speeds depend upon the masses of the constituent atoms of the molecule and their positions, from a measurement of these absorption frequencies, (which are therefore characteristic of each molecule), one can work back and obtain the relative positions of the atoms; that is, one can evaluate the bond lengths and bond angles of the molecule concerned from the accurately known masses of the atoms. The only condition required for the observation of such spectra is that the molecule must possess a permanent electric dipole moment. The interaction of the dipole moment with an externally applied electric field—known as Stark effect—is utilized not only to enhance the sensitivity of the instrument by the application of an alternating electric field, but also serves as a useful technique for the identification of the spectra and the measurement of the dipole moment of the molecule.

Sometimes the spectra observed show some fine structure caused by: (*a*) a nucleus in the molecule having a deformed charge distribution or (*b*) internal rotation in which one part of the molecule would rotate with respect to the rest of the molecule. Studies of such spectra provide information on the electronic structure of the molecule and also concerning the barriers hindering the rotation of a part of the molecule. Many a time it is also possible to observe the excited vibrational states of the molecule which can then be used to get more information regarding the molecular constants.

In TIFR for these studies a 100 KHz Stark Modulated Microwave Spectrometer has been fabricated and the energies, (frequencies), corresponding to the transitions are measured very accurately, to one part in a million, with a frequency standard built here. Investigations with these instruments have enabled a determination of the geometry of pentafluorobenzonitrile, fluorobenzene, 2-cyanopyridine, etc.

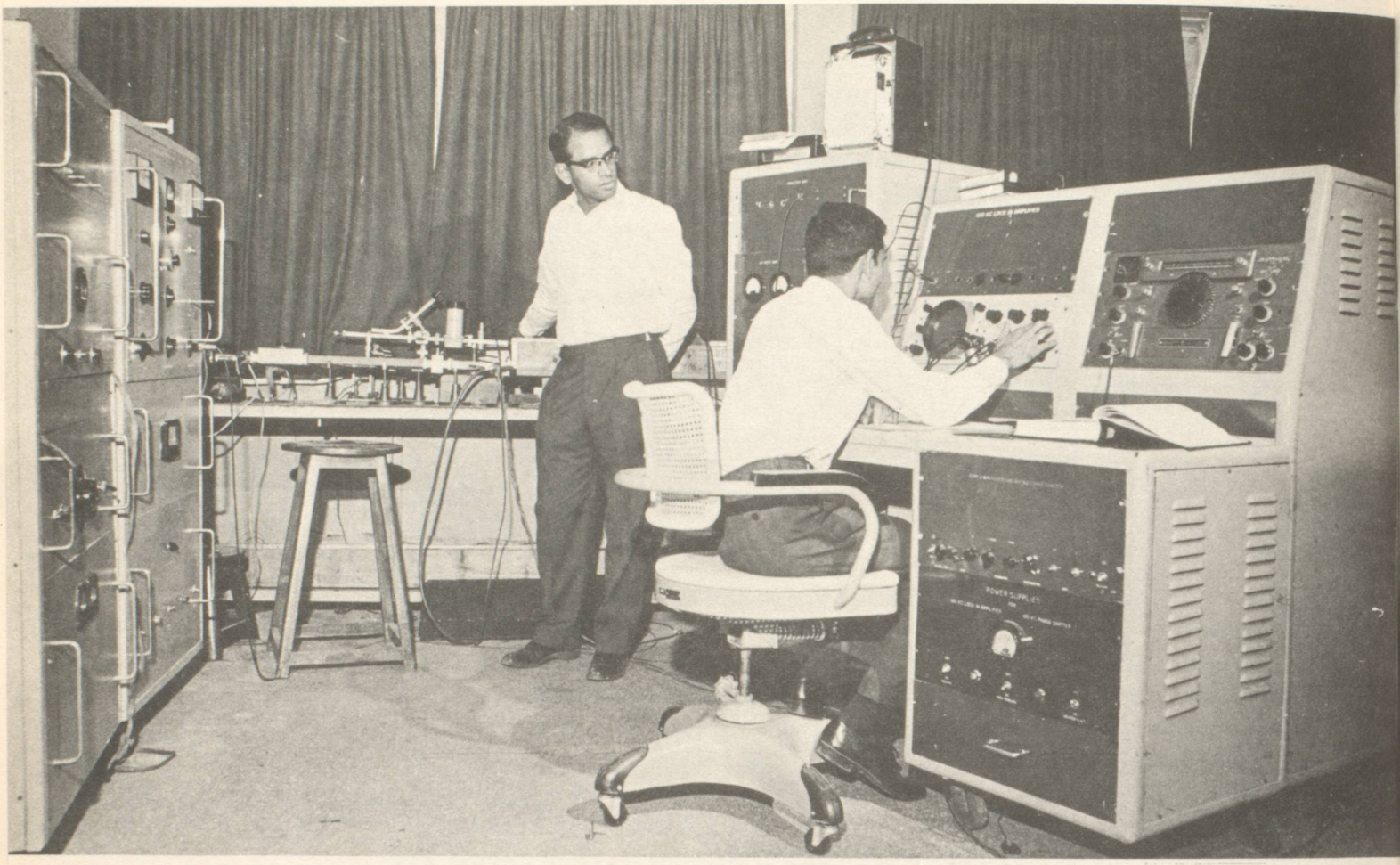


Fig. 6—Microwave Spectrometer, (8 GHz to 50 GHz), with 100 KHz Stark Modulation for study of Rotational Spectra of Molecules in the Gaseous State. The locally fabricated spectrometer is shown here with a frequency standard (one part in 10^8) which was also assembled at the Institute. Rotational Spectra of substituted oromatic hydrocarbons along with quadruple and dipole moment measurements have yielded interesting structural information on these molecules.

Theoretical Chemistry

The role of chemical structure in deciding the physical and chemical properties of a compound has been emphasized earlier. One would like to understand in detail the kind of forces that endow a compound with its geometry and structure and thereby its physical and chemical properties. In essence, one should be able to derive the properties of a compound from first principles given the basic electron-electron, electron-nucleus and nucleus-nucleus interactions. However, such a task is formidable even with present-day computers, and chemists have had to adopt reasonable approximate methods in working towards such an understanding. Theoretical work in chemistry at TIFR has been directed towards an understanding of

the magnetic and other properties that are measured experimentally; in fact, theory and experiment go hand in hand. Besides this programme, theoretical investigations have recently been initiated in a field that is sometimes termed "Quantum Biophysics".

Biological processes take place through chemical reactions. Using some of the approximate methods mentioned above, attempts are being made to predict the shape of proteins and polypeptides since it is well known that the specificity of behaviour of biomolecules is often correlated with their shapes. For example, such calculations predict that polypeptides should in general attain a regular helical structure and also explain why *cis* peptides do not occur in nature. Biologically important nucleic acids and polysaccharides are currently under study.

CHEMICAL PHYSICS

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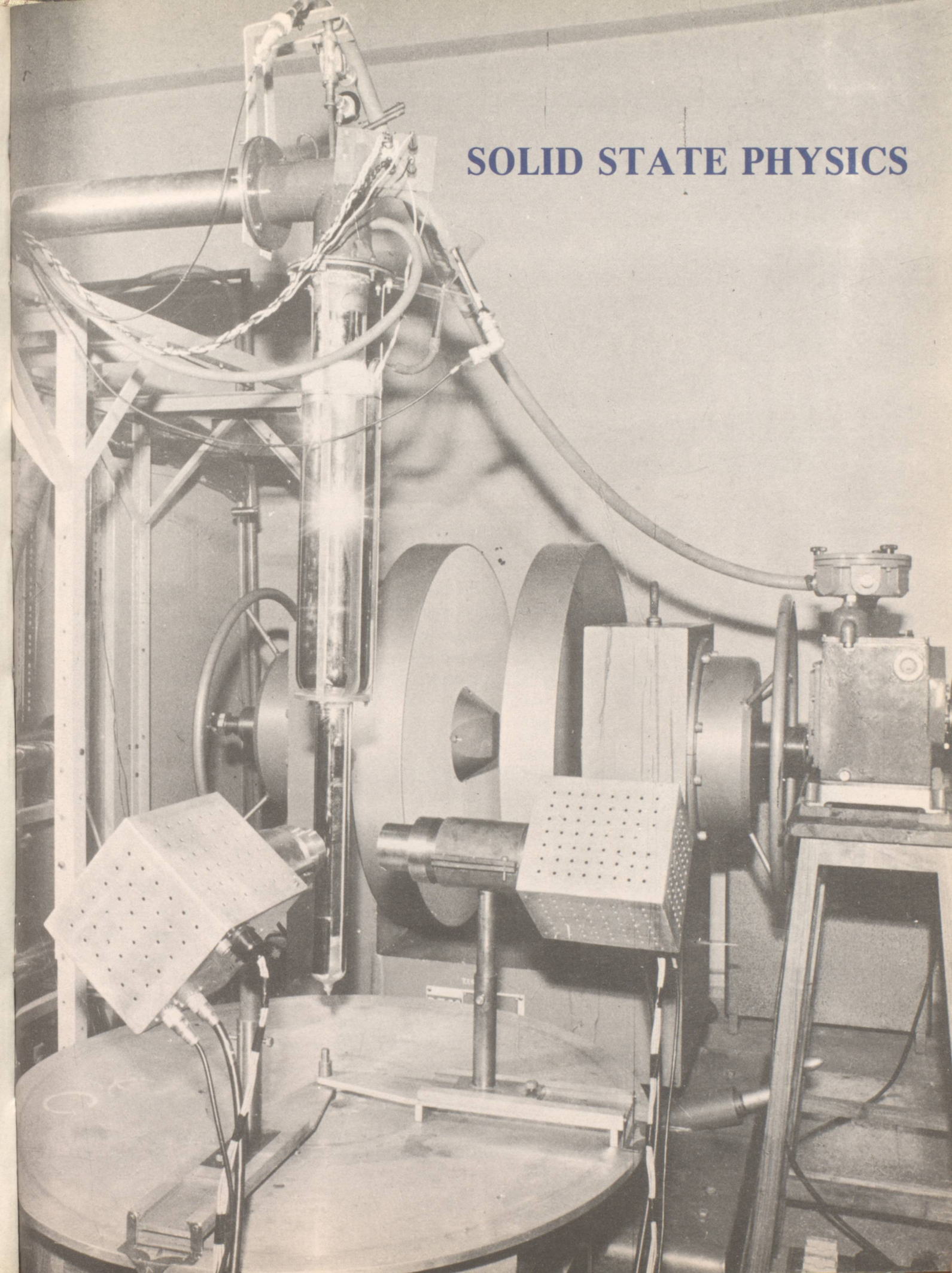
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SOLID STATE PHYSICS

SOLID STATE PHYSICS

Research in border-line areas between Nuclear and Solid State Physics developed in various groups in the Institute, engaged primarily with nuclear physics research using different nuclear techniques, over the decade 1960-1970. To bring these activities together in one group, Solid State Physics group was formally created as a new group, around 1967. Until then, these nuclear techniques were being used mainly for nuclear structure studies and as occasion arose, for the study of solid state problems, using radio-active nuclei as probes. Thus in the Nuclear Spectroscopy group, Solid State studies were developed using the following nuclear techniques: (1) Nuclear Orientation at low temperatures (2) Mössbauer spectrometry (3) Perturbed Angular Correlation of gamma-rays and (4) Positron Annihilation.

Similarly, out of the activities in the group using mainly Nuclear Magnetic Resonance (NMR) techniques, arose two groups: Chemical Physics group, using high resolution NMR and the group devoting its efforts to the study of magnetic properties of solids, using wide-line NMR. Investigations in other related areas like defects in solids and ultra-sonic attenuation in solids have also been carried out.

In course of time, important facilities were installed as aids to solid state research. These were: X-ray Diffraction Unit (1967), Electron Microscope (1967) and Liquid Nitrogen (1969) and Helium Plants (1962). Irradiation facilities used for radiation damage studies include 3-MeV electron linear accelerator and 3000 Curie-Cobalt-60 source for gamma irradiation.

N.M.R. Studies

The nuclear magnetic resonance (NMR) group was started in 1953 when Prof. S.S. Dharmatti returned from USA after working with Prof. Falix Bloch, the Nobel Prize winner for discovering NMR. Starting with one research student, a wide line NMR spectrometer was built in late fifties which was as sensitive as the best commercial spectrometer. Using this spectrometer, chemical shifts of nuclei were measured in various organic systems and a correlation was made between the nature of bond and the shift. Similarly molecular and chemical structures were investigated in borates, glycines and cobalt complexes, using temperature as a variable parameter.

Laboratory for adiabatic demagnetisation set up for nuclear orientation studies at very low temperatures (10 mK-100 mK).

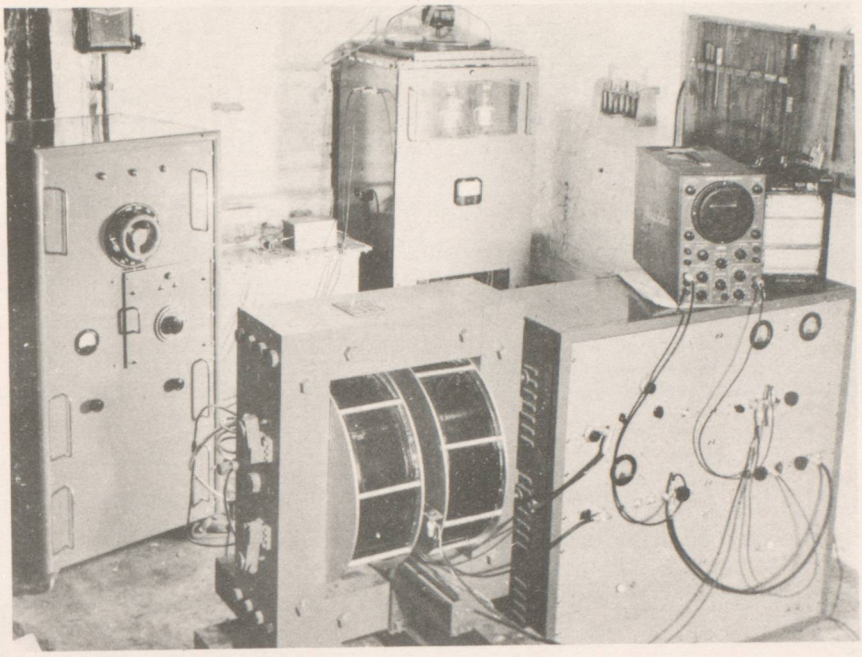


Fig. 1—Wide Line Nuclear Magnetic Resonance Spectrometer and Electromagnet with 4 KVA Power Supply.

Interest in metal physics grew after the discovery that in a transition metal platinum, a negative spin density was found to exist at the nucleus, contrary to the usual positive spin density in normal metals. This group was the first to predict that the bulk paramagnetic susceptibility due to unfilled d band electrons was responsible for this anomalous shift. It was proved subsequently by this group that by alloying the metal with tin, lead, silver and mercury, the d band susceptibility as well as negative spin density decreased. The Knight shift plotted against the susceptibility was a straight line with the slope giving the hyperfine field per d spin. These results were checked with theoretical predictions. In this work the macroscopic property is correlated with microscopic property.

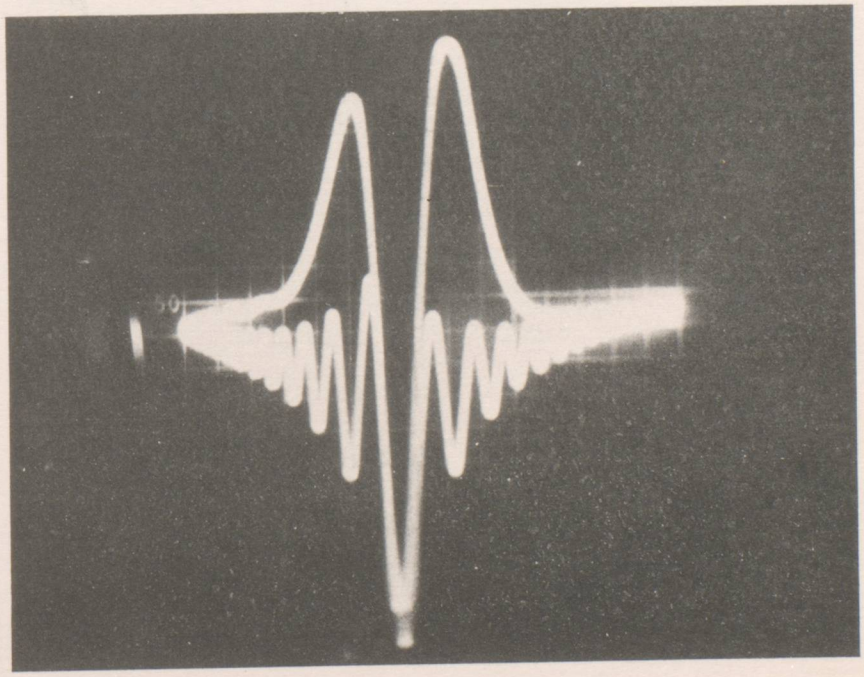


Fig. 2—Na^{23} Resonance in NaOH Solution.

Subsequently, the type of conduction electron spin polarisation by the moment of the rare earths was investigated in several systems to understand the basic nature of rare earth magnetism. It was shown, using rare earth platinum alloys, that the polarisation is oscillatory in character. This result is fundamental since many basic theories in magnetism utilise the property of either oscillatory or uniform character of spin density oscillation. It was also shown that in Cerium alloys the proportionality between susceptibility and the spin density breaks down due to the proximity of f electron to the Fermi surface and a high temperature "Kondo system" was shown to exist in $CeSn_3$ alloy.

A Spin-echo spectrometer was built which could measure the relaxation time T_1 of protons in liquids. Using this, the T_1 of protons in liquid crystals and tissues was measured as a function of temperature. The nature of water molecules in liquid crystals and tissues have been analysed. Similarly a pure quadrupole resonance spectrometer and Zero field NMR spectrometer were

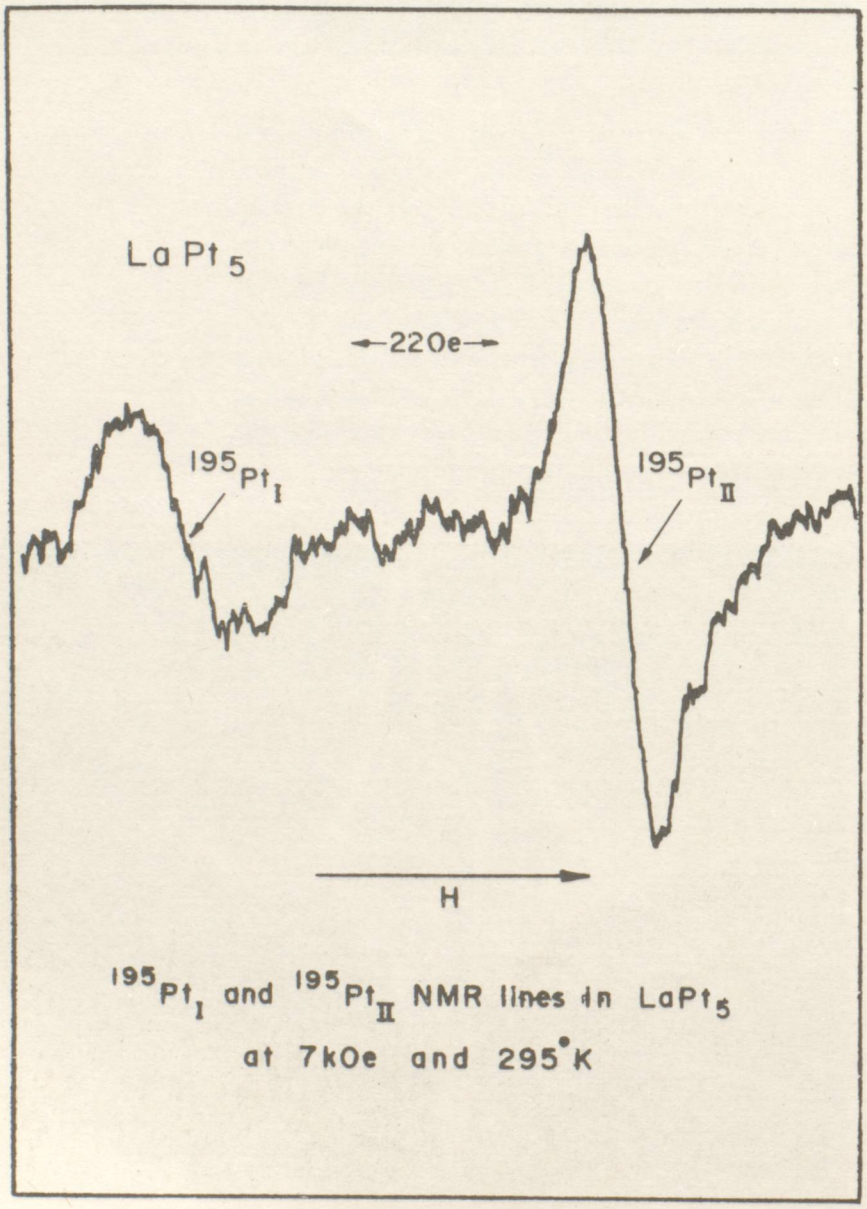


Fig. 3—Experimental evidence for Oscillatory Character of Conduction Electron Polarisation in Alloys.

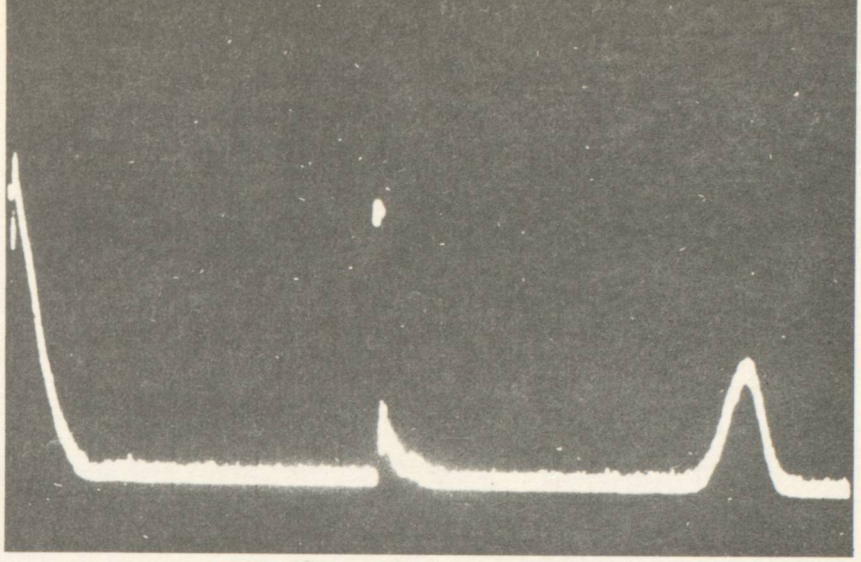


Fig. 4—Spin Echo Signal of Protons in Glycerine Using Pulsed NMR Spectrometer.

built to investigate the ferroelectrics and ferromagnets. The internal hyperfine fields in ferromagnets as a function of temperature were measured in several Heusler alloys and checked with the theories of Friedel and Blandir. In ferroelectrics, the effect of soft mode was shown unambiguously in hydrogen bonded KDP system. This is usually accessible only to laser Raman spectra.

In liquid alloys, this group, by measuring the shifts and quadrupolar interaction, was able to show the effect of short range order which exists in disordered system. The results obtained by NMR were always cross-checked with those of other microscopic techniques to obtain an internal consistency and a unified picture of the solid state system. The magnetic properties of samarium alloys were thus investigated using many techniques. It was shown that the peculiar magnetic properties of Sm alloys are due to the existence of higher excited state close to the ground state and the mixing of these states by strong crystal fields. These results have been accepted as specially significant since some of them have technological applications like improving the strength of permanent magnets made of $SmCo_5$ alloys.

Nuclear Orientation at very low temperatures

The technique of adiabatic demagnetisation of electronic spins in paramagnetic salts was developed, and the complete laboratory was set up in 1963. The lowest lattice temperature of 10 mK of CrK alum was obtained. The problems of good thermal contact between the cooling salt and metallic samples to be studied, insulation of the assembly and accurate thermometry were taken up. Considerable effort was put in tackling these problems. Stationary temperature in mK region cannot be obtained by this technique as it is a one shot process. The lowest rate of rise in temperature of the salt was obtained to be of the order of 10 mK per hour which is comparable to that achieved in any other laboratory.

The traditional method of measuring temperatures in this region was to measure paramagnetic susceptibility of CrK alum and to correct for large deviations from Curie-Weiss law. This correction resulted in a large error in temperature determination. Nuclear technique was applied for this purpose. Co^{60} nuclei were aligned in a single crystal of hcp cobalt along the c-axis which is the easy axis and all magnetic domains are spontaneously aligned along this axis. No external magnetic field is required which simplifies the experimental

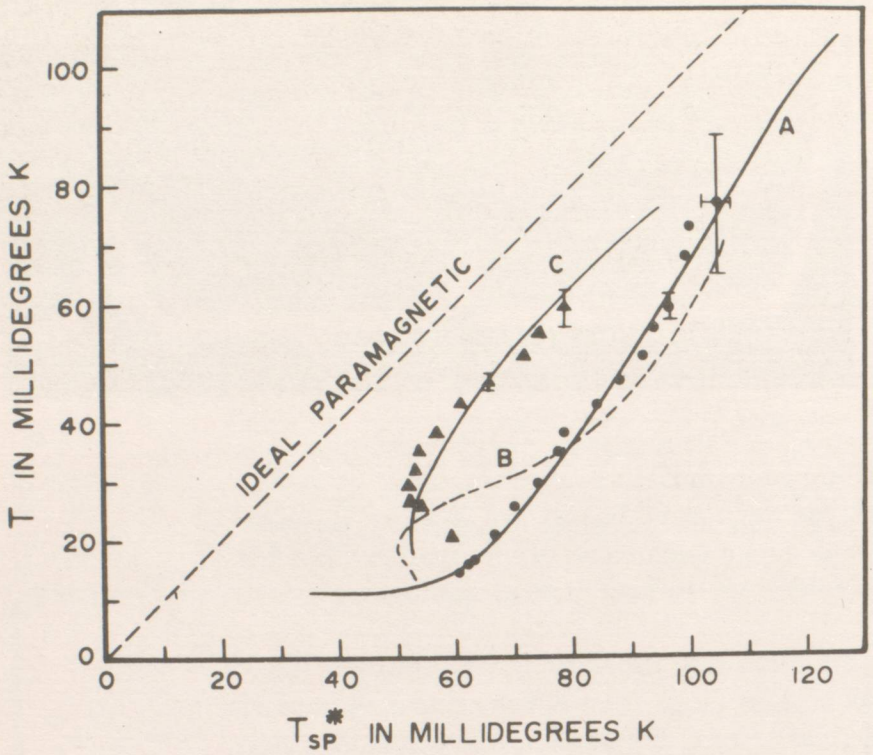


Fig. 5—Absolute temperature scales of two paramagnetic salts—Cr Potassium alum (•) and Cr Methylamine alum (Δ) determined by nuclear orientation studies as compared with thermodynamic determinations.

arrangement. From the angular distribution of gamma radiations from aligned Co^{60} nuclei the absolute temperature could be determined very accurately and this was compared with the simultaneous measurement of susceptibility of two paramagnetic salts—CrK alum and Chrome methylamine alum. These studies established unambiguously absolute temperature scales of these salts in the region of 12-80 mK. The effect of the shape of a single crystal of cobalt on the temperature determined was also studied and it was shown that due to the presence of large volume of closure domains present in a disc-shaped crystal it is necessary to use a rectangular crystal.

Nuclei of In^{114} and Co^{57} were diffused in a single crystal of cobalt and aligned at very low temperatures. For studies of hyperfine fields in polycrystalline metals and alloys external magnetic fields upto about 10 kilogauss are required. Two methods have been employed for this purpose. A Nb cylinder was used to obtain the magnetic field by trapping the flux in the cylinder in the superconducting state. This method gave a maximum trapped magnetic field of 1800 gauss. Higher fields upto 10 kilogauss were obtained from a Nb-Zr superconducting solenoid. Studies of hyperfine fields at Mn nuclei in Ni-Mn system have been undertaken in order to correlate with the results obtained by Mössbauer spectroscopy.

Properties of superfluid helium

Study of flow rates of superfluid helium film along a glass substrate were carried out as a function of pressure heads upto 30 cms and at various temperatures between 1° and 2° K. Two important new results were obtained (a) the

flow rate is independent of pressure head contrary to the expectations on the basis of studies upto 4 cms of pressure heads at Clarendon Laboratory, Oxford and (b) abrupt jumps in the flow rates were observed which were attributed to change in rate of production of vortices.

Mössbauer Spectroscopy

The Mössbauer studies were initiated soon after the discovery of this new effect, the recoilless resonance absorption of gamma rays in 1958. The first experimental observation in this laboratory was made in 1961 with the 26 KeV gamma transition in ^{161}Dy obtained from the β-decay of ^{161}Tb. The percentages of recoilless emission and absorption were estimated for Dysprosium. Gradually the Mössbauer experimental facility consisting of Mössbauer drive, radioactive source preparation, cryogenic and vacuum technique, proportional counters and associated electronics has been developed. To widen the scope further so as to arrive at the second moment of the displacement of an atom in a lattice, through the Debye-Waller factor, the complete absorption technique was developed for wider line width systems, such as $FeSn_2$, $FeSn_3$, etc. using Lithium and Ammonium fluoroferrates. Variety of measurements have been made to cover a wide range of solid state properties such as study of lattice distortion, magnetic ordering, relaxation and superparamagnetic effects, magneto crystalline anisotropy, etc.

In order to study the relationship between co-operative lattice distortion and antiferromagnetic ordering, the hyperfine field and quadrupole interactions at the iron nucleus in $KFeF_3$, below the Neil temperature of 115° K, were studied. The direction of magnetisation at the site of Fe nucleus could be predicted from

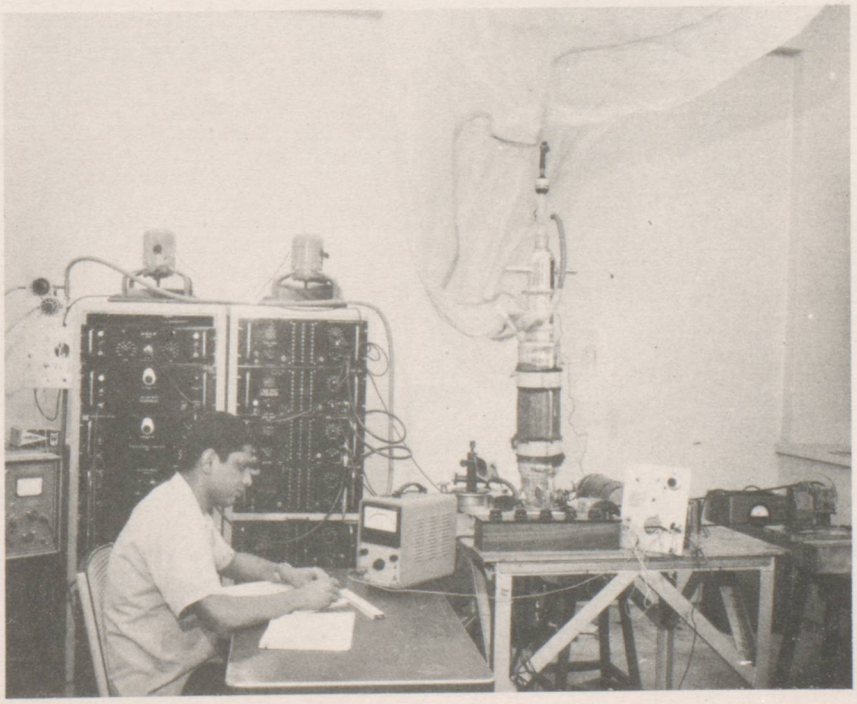


Fig. 6—First Cam driven constant velocity Mössbauer spectrometer completely built in the Institute along with liquid helium cryostat. Study of unquenched orbital angular momentum in the solid $KFeF_3$ is being carried out in the temperature range 4.2°K to 300°K.

the existence of unquenched angular momentum and the spin. Also, from the determination of Eigen states and Eigen values of the wave functions involving the exchange and spin-orbit coupling it was possible to predict and verify the observed variation of hyperfine field and the quadrupole splitting with respect to temperature.

An interesting case of zero hyperfine field at the Fe nucleus, when the substance was magnetically ordered was observed in the system of FeMnGe where neutron diffraction studies appeared to contradict the Mössbauer result. A plausible explanation of this was offered in terms of the time of observation in dynamic spin systems.

Another set of Mössbauer measurements have been carried out to study the spin Dynamics in paramagnetic and magnetically ordered substances. Detailed investigations in Fe_2O_3 Al_2O_3 and Cr_2O_3-Fe_2O_3 systems have been made. The observed anomalous shapes of Mössbauer spectra are explained on the basis of the time dependent hyperfine interaction of nuclei with their environ-

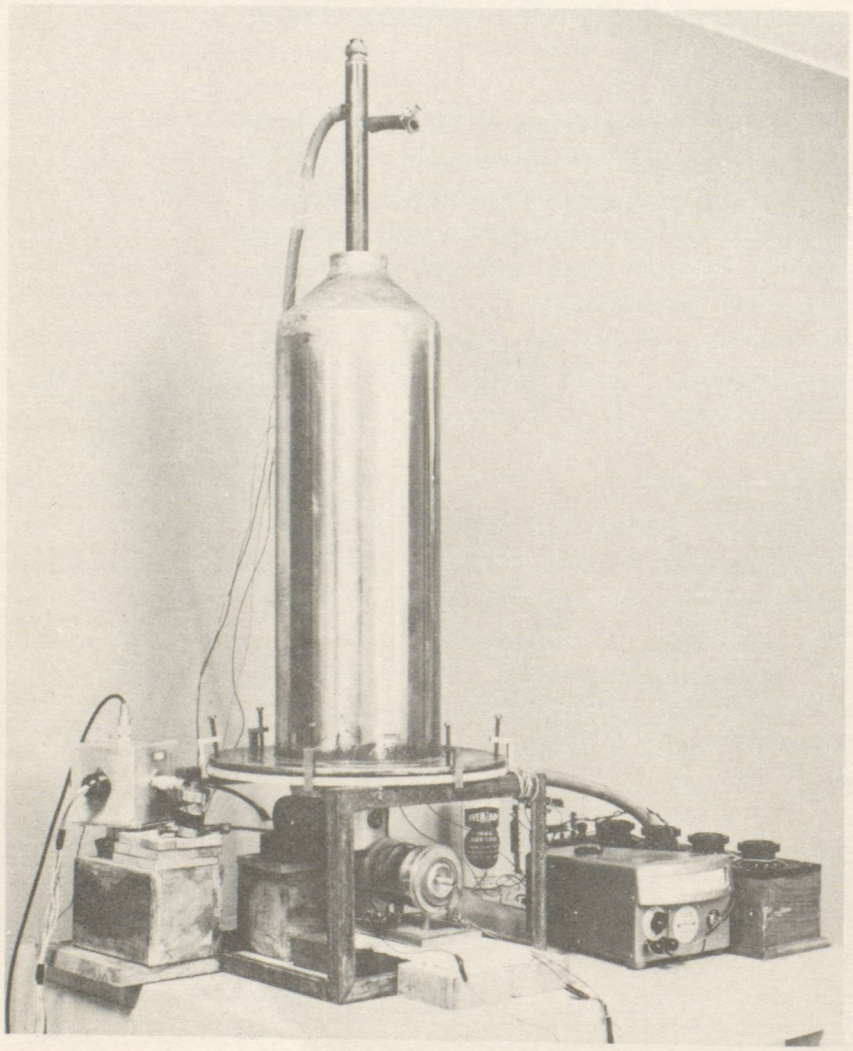


Fig. 7—A home-built electromagnetic sinusoidal Mossbauer drive along with a metal liquid helium cryostat for carrying out the measurements in the temperature range 4.2°K—300°K.

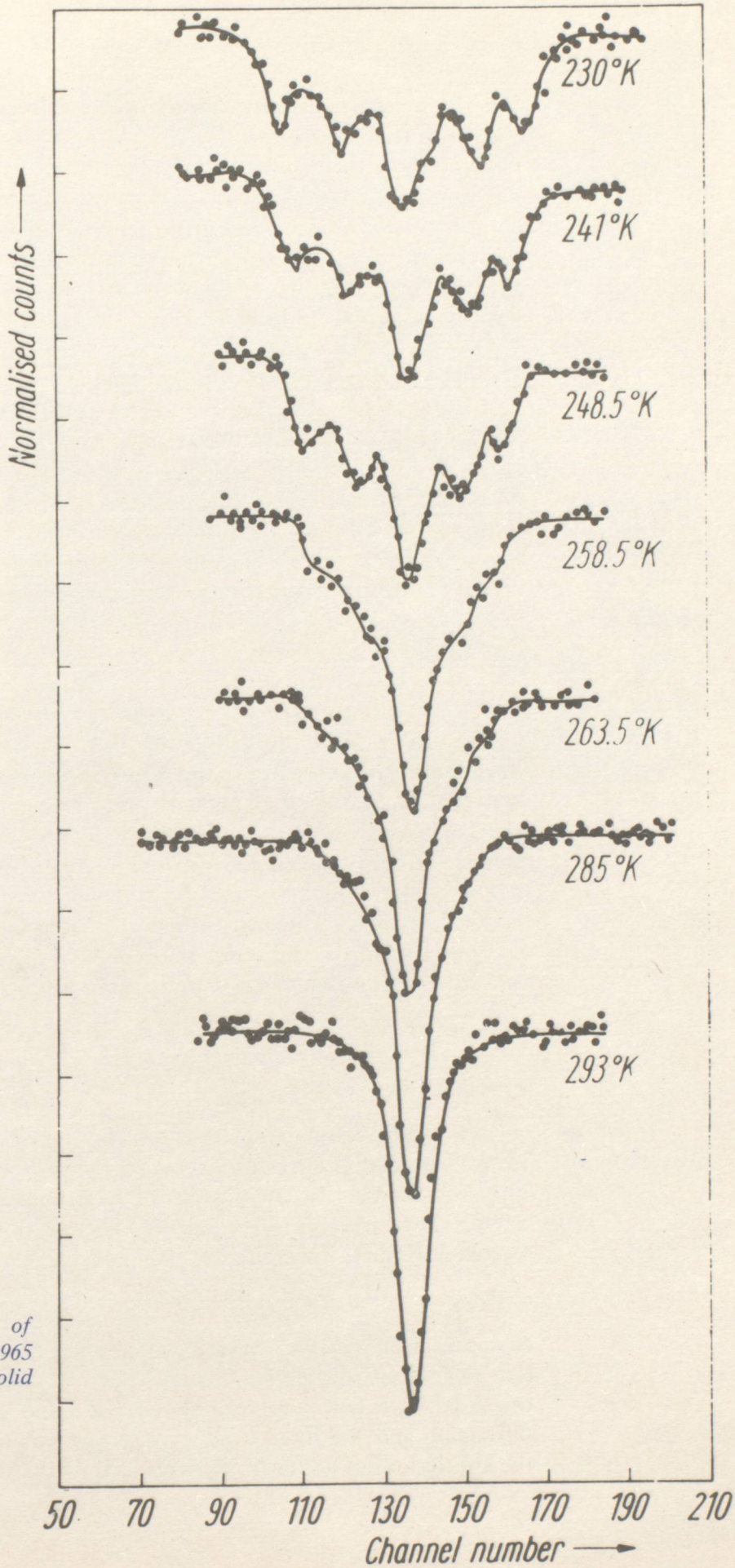


Fig. 8—Anamolous shapes of the Mössbauer spectra of 0.965 Cr_2O_3 — 0.035 Fe_2O_3 solid solution.

ment. Such interactions where the spin dynamics of the ions individually or collectively plays an important role arise via (a) the electronic relaxation effects and (b) superparamagnetic effects. These effects are expected to depend on a variety of factors such as various heat treatments given to the system, $Fe^{3}+$ ion concentration, their binding in the host lattice, relative ionic radii of the diffusing species and the host lattice ions, etc. Systematic studies in (1-x) Cr_2O_3-xFe_2O_3 system in the temperature range 10° K to 293° K have unambiguously shown that in this system the anomalous shapes of Mössbauer spectra arise due to incomplete annealing of the sample. Further work in this direction to investigate the relaxation and superparamagnetic effects is continuing.

The behaviour of magnetocrystalline anisotropy in Ni single crystal has been a controversial subject for several years. Some authors believed that there was a change of direction of easy magnetisation from $< 111 >$ to $< 110 >$ at about 355°K and then to $< 100 >$ at about 375°K whereas others believed that it changed from $< 111 >$ to $< 100 >$ at 470°K. The technique of Mössbauer spectroscopy was first applied to this problem in this laboratory and from the measurements of relative intensities of Mössbauer lines for Fe^{57} nuclei in a single crystal of Ni at different temperatures and in different crystallographic directions it was unambiguously shown that the direction of easy magnetisation changes from $< 111 >$ to $< 100 >$ at 490°K.

The problem of atomic ordering was studied on a microscopic scale in NiMn system by studying the temperature dependence and distribution of hyperfine fields at Fe^{57} nuclei in these alloys with Mn concentrations ranging between 2 and 33 at.%. This is the best system as it shows the most dramatic effect of change of degree of atomic ordering on its magnetic properties. The spectra showed co-existence of long-range ordered and disordered phases whose relative volumes could be controlled by various heat treatments. The saturation hyperfine field was found to be independent of host magnetic moment showing that the contribution of conduction electron polarisation to the hyperfine field was negligibly small and atomic moment of Fe^{57} in this system is the same as in pure Ni. Further extensive study of this system is continuing.

Positron Annihilation studies

Positrons Annihilation as a tool for investigating the condensed state of matter had been of interest for some time, especially since the forties. The mechanism and the rates of annihilation of positronium atoms in different solid state environments have been the subjects of these investigations. Such studies were started in Nuclear Spectroscopy group around 1964.

The delayed component (τ_2) and its intensity (I_2) in the lifetime spectra of positrons annihilating in various molecular materials were studied using slow fast coincidence technique. These studies of positron lifetimes which were of the order of a few nano-seconds yielded some important results. Also, X-ray diffraction and E.S.R. data were collected, when found necessary, to support the conclusions of the main investigations.

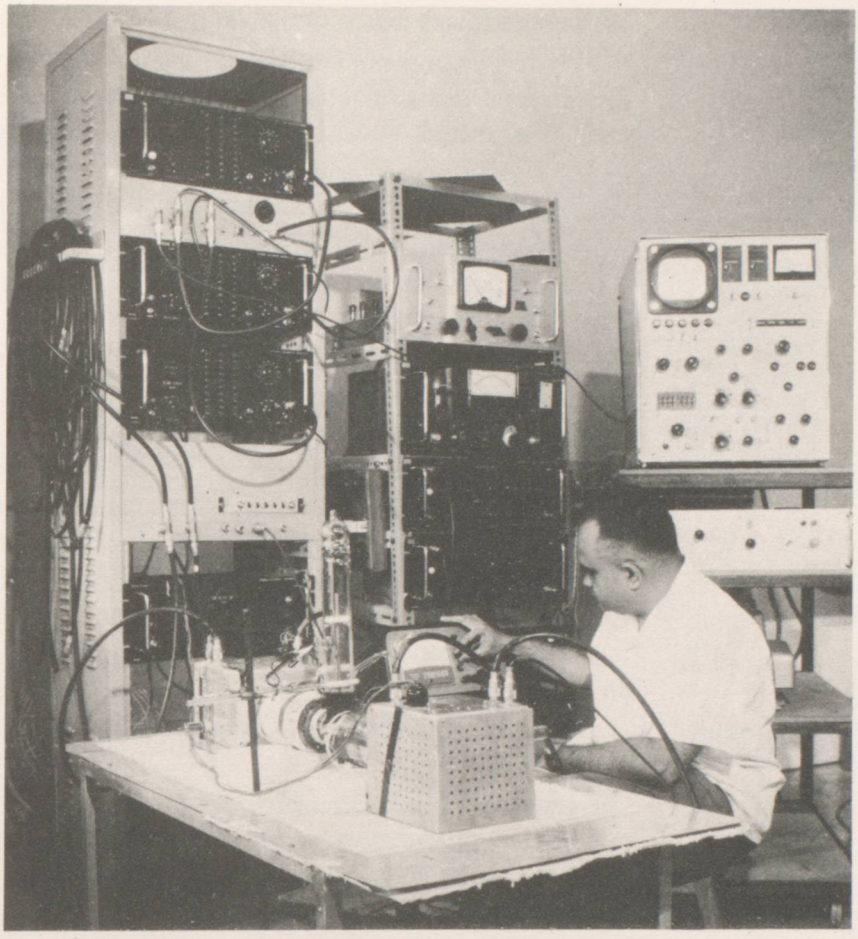


Fig. 9—Experimental set-up for measuring life-times of positronium atoms in condensed matter.

Radiation damage effects produced in polymers like PTFE, polyethylene, polystyrene by Co^{60} gamma rays and thermal neutrons were studied to obtain useful information regarding possible annihilation sites of positrons in these substances. A free volume model for the formation and quenching of positronium atoms, which predicted a certain correlation between I_2 and τ_2 in molecular materials, was developed. The predicted correlation was experimentally confirmed on the basis of the annihilation data for various molecular liquids, polymers and crystals.

The free volume model and the set of correlation curves served a useful framework in understanding the data obtained for materials like arsenic oxide, antimony oxide, trioxane, polyoxymethylene, sulphur in crystalline and polymer forms, materials subjected to processes of annealing and quenching, etc. Also, it became possible to interpret some positron data in literature regarding chemical isomers, temperature dependence of three gamma emission rate in PTFE, melting of naphthalene, and glass-transition in polyethylene (Marlex 50) etc. on the basis of the free volume model.

The relationship between τ_2 , I_2 density and phase changes in the molecular materials became apparent through these studies and led to investigations

of the behaviour of positrons annihilating in the surroundings of a liquid state. Problems relating to deoxygenating of liquids, their transfer in vacuum, and maintaining them in a degassed state under controlled conditions during data collection were successfully solved. A correlation between changes in viscosity and τ_2 with temperature in simple alkanes like n-Octane, n-Hexadecane etc. was established. The study of simple molecular liquids held a good promise by the end of 1970, and its natural extension to polar and associated liquids became a fruitful research programme during subsequent years.

Ultrasonic Studies

Ultrasonic investigations for the study of solids were started during the year 1963-64. By ultrasonics in MHz range of frequencies one measures the attenuation and velocity of sound wave as a function of temperature, pressure, magnetic field, etc. in a medium. From these measurements information about the various properties of the medium is obtained.

Two aspects of ultrasonic studies were investigated in this laboratory in some detail: (1) Interaction of domain walls in ferromagnetic materials, (2) Studies of phase transition in magnetic and other materials.

Domain walls in ferromagnetic materials cause an increase in ultrasonic absorption and a decrease in velocity. A measure of this can be obtained by applying a small magnetic field to make the material a single domain structure. A number of experiments were carried out in ferromagnetic nickel and nickel-iron alloys with variation in magnetic field, pressure and temperature to elucidate the nature of this interaction.

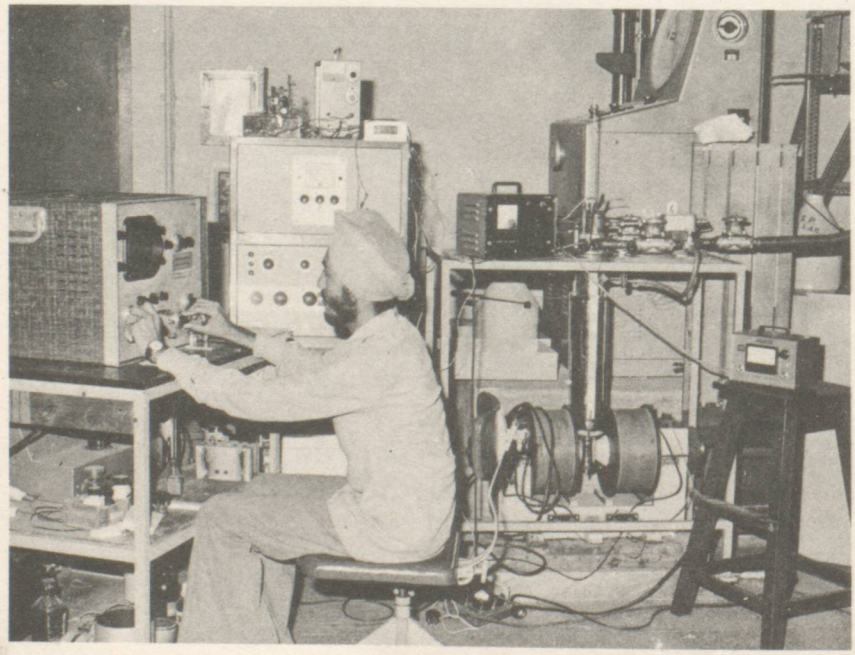


Fig. 10.—Experimental set-up for the measurement of energy gap in superconductors by ultrasonics. The He cryostat is towards the right hand side. On the left hand side all the apparatus are for the measurement and control of temperature. The person is adjusting the attenuation comparator for sound attenuation measurement.

The studies of phase transition in solid state physics is of recent origin. As a solid undergoes phase transition there is a realignment of forces in the medium. This realignment does not take place suddenly but slowly over a temperature range. There are certain models and laws which predict how this realignment should take place. The studies of phase transition involve experiments which will examine the models and laws and thereby, gain insight into the mechanism of phase transition. Ultrasonics is a powerful tool for giving information for both static and dynamical aspects of phase transition.

Experimentally, any investigation with phase transition requires measurements of the properties of the system with temperature control and stability in the millidegree region. These measurement systems were set up in the laboratory and several experiments were performed in nickel near its curie temperature (350°C). For this purpose equipments like ultrasonic comparaters, precise velocity measuring devices and automatic measuring system for ultrasonic attenuation were also developed.

Defects in solids

All solids have structural defects in some form or the other. The primary defect called point defects and those of higher order derived from them essentially determine the macroscopic properties of the solids. In addition to these intrinsic defects, it is possible to induce defects in large numbers are varieties by subjecting solids to heat treatment or ionizing radiations. The radiation, in particular, can provide a powerful tool for modifying the properties of solids to suit their applications in everyday life. The studies of these defects have therefore been of great importance not only from the point of view of physics alone, but also because of their importance in material technology.

Lead halides: Investigations were carried out on point-defects in lead halides. The lead halides belong to a group of solids which exhibit striking behaviour when radiated with photons, electrons, and other ionizing radiations. They tend to decompose in a manner similar to silver halides which are extensively used as materials for photographic emulsions. It was, therefore, of interest to see if these materials can be used as substitutes for the silver halides based emulsions.

An extensive study programme was, therefore, taken up. The studies were aimed at (1) measurement of efficiencies of production of defects. (2) their physical nature and (3) the efficiency with which they diffuse to produce their by-products.

It was observed that a point defect such as a colour centre can be produced at an expense of nominal energy 3 ev, in lead chloride, lead bromide, and lead iodide. The colour centres in PbF however, need slightly more energy and show different behaviour. In addition, the centres lead to formation of clusters as seen from their ESR lines which are narrowed due to exchange interaction. This behaviour of colour centres in the lead halides at liquid nitrogen tempera-

ture is unique. This was corroborated by observations by an electron microscope which showed that the vacancies tend to form dislocation loops at liquid nitrogen temperature. On warming to room temperature, extensive vacancy clustering in the crystals was observed. The optical absorptions corresponding to these centres were also observed. The behaviour of the defects in these materials indicates that the lead halides can be used as photographic emulsion material for applications where speed is not much of a concern.

The rapidity with which the vacancies agglomerate indicates, that the diffusion of vacancies would be very fast and hence an extensive study of self diffusion of anions and ionic conductivity in these materials has been planned. The technique to be used for evaluating the self-diffusion of anions consists of measurement of the amount of radioactive isotope of the halogen released from the solid in contrast with corresponding stable halogen gas.

Alkali halides: The photo-luminescence and the scintillation emission from single crystal of NaI(Tl) etc., were investigated spectroscopically using specially developed ultra-violet filters. The scintillation spectra excited by Co^{60} gamma rays were studied using Steinheil spectrograph. The luminescence decay times were also measured band-wise and at different temperatures by fast pulse techniques.

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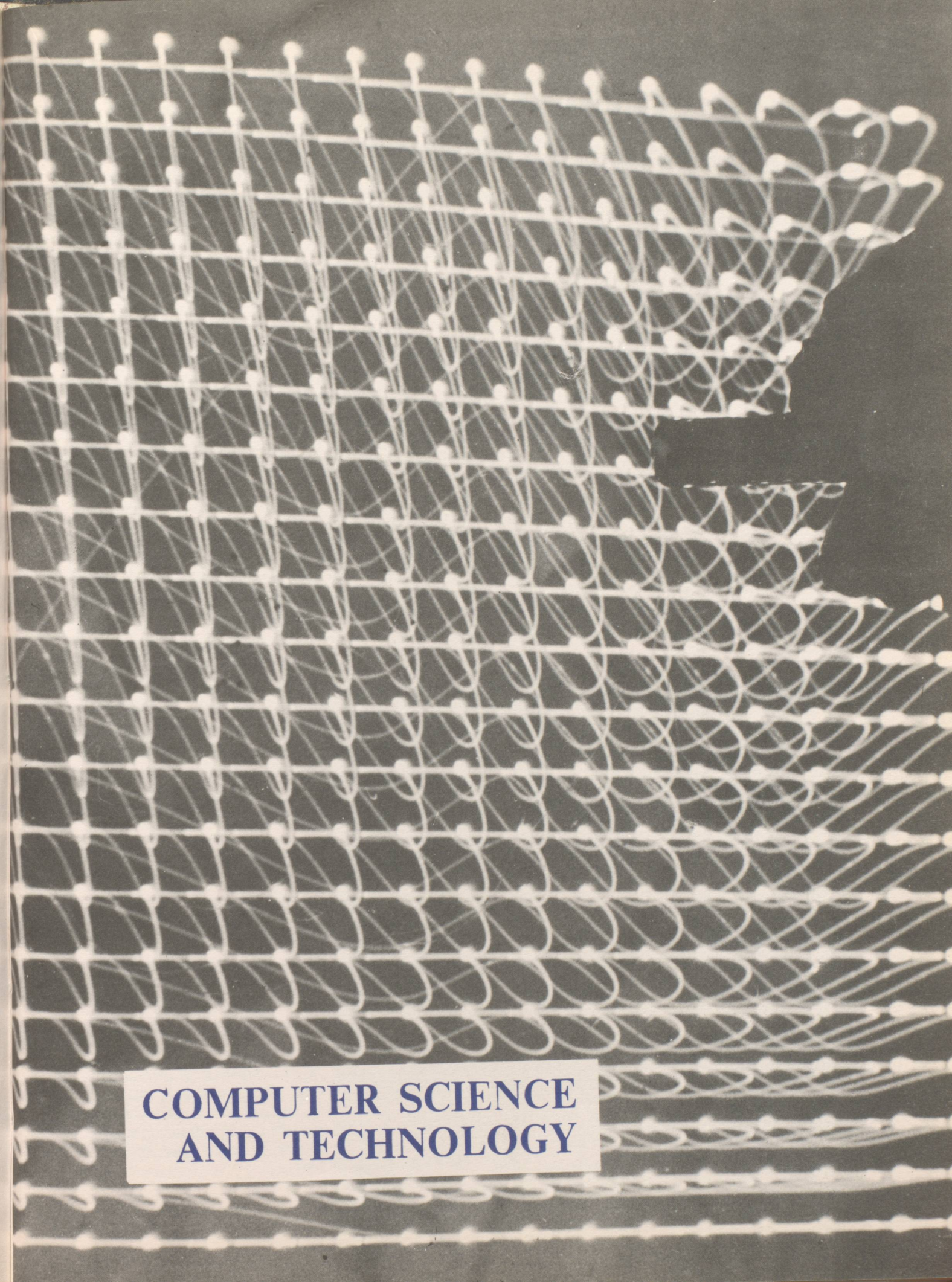
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COMPUTER SCIENCE AND TECHNOLOGY

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Designing and Building TIFRAC

The first ten years: 1954-1964

Activity in the area of computer science and technology started in 1954 as one aspect of the development work of the Instrumentation Group. After some preliminary efforts at building digital logic sub-assemblies, a decision was taken, towards the end of 1954, to design and build a full-scale, general purpose, electronic digital computer. At the initial stages, the total number of persons working on this project was about six, most of whom had an M.Sc. in Physics with specialization in electronics. Except for one member, none had been outside India, and none of the participants in the project had had any experience in either using a computer or operating one, let alone building one.

In these circumstances, it seemed prudent to go about the task in two phases. The first phase would involve the design and construction of a pilot machine which would serve as a proving ground for ideas in circuit and logical system design; engineering design and fabrication techniques could also be tried out in putting together the pilot model. Based on this experience, and making use of the personnel recruited and trained on the job in the first phase, a full-scale computer could be designed and built in the second phase.

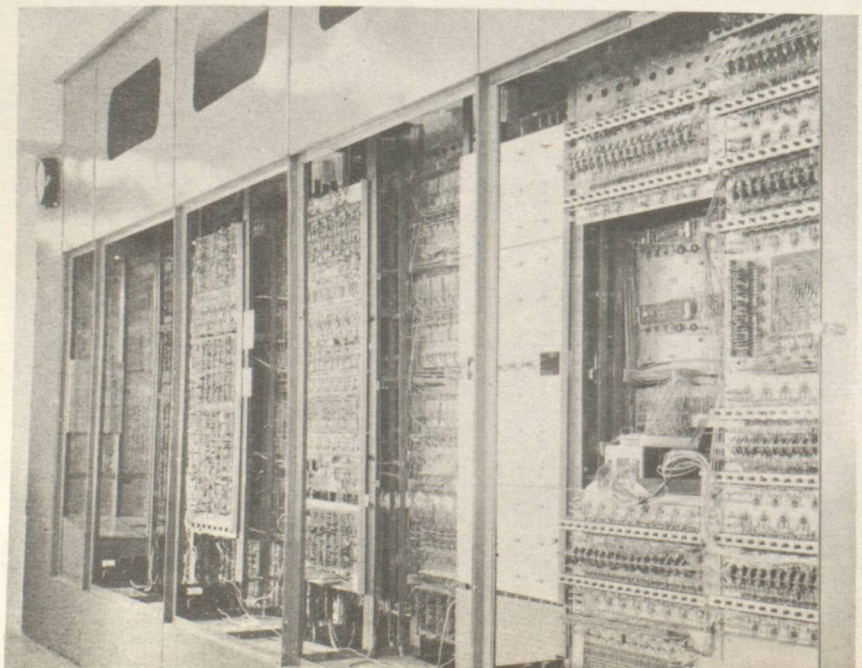


Fig. 1 — TIFRAC, a general purpose digital computer designed by the Computer Group of TIFR: the first electronic computer to be designed and built in India.

The design work on the pilot machine was started early in 1955, and by October 1956, it was operational. Design on the full-scale version was started early in 1957 and its fabrication was completed early in 1959. It was commissioned in February 1960. This computer was subsequently named TIFRAC in 1962 when the new TIFR buildings were inaugurated by Prime Minister Jawaharlal Nehru.

Evaluation of the Accomplishment

To evalute properly the significance of what was accomplished by the TIFRAC project in terms of know-how in computer technology, it is worth comparing TIFRAC with some of the first generation computers built in the USA. In Table I are summarised the principal features of the Princeton computer (IAS) built by von Neumann, the IBM 701, the pilot machine built at TIFR, and TIFRAC. From this table, some instructive conclusions can be drawn.

To begin with, it will be seen that the pilot machine design, except for its size, was quite in pace with the state of the art for 1954. The design of TIFRAC in 1957 was still not very much behind what was being attempted at that time elsewhere. But by the time it was commissioned early in 1960,

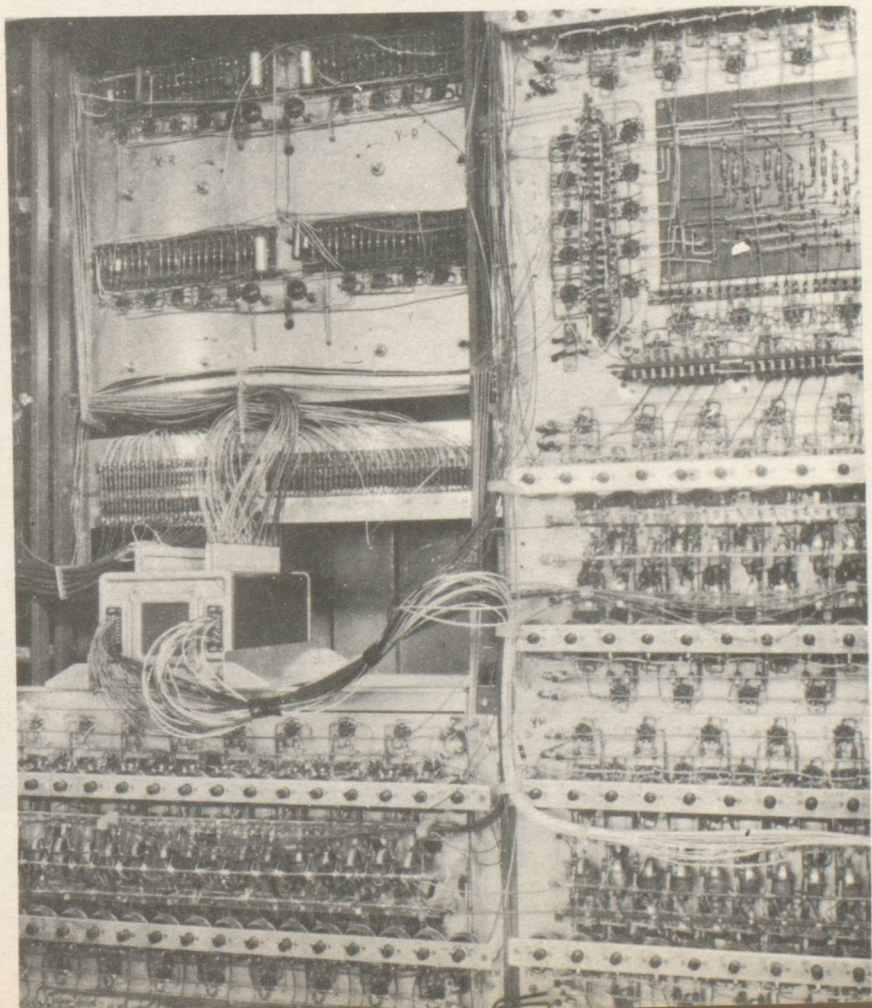


Fig. 2—The Core Memory: The magnetic core memory of TIFRAC had a capacity of 1024 words, and was later expanded to 2048 words.

Table I. A Comparison Between 4 First Generation Computers

	Institute of Advanced Study, Princeton	**IBM 701**	**T.I.F.R. Pilot Machine**	**TIFRAC**
1. Date Started	1946	1950	1955	1957
2. Date Commissioned	1952 (June)	1952 (production delivery)	1956 (Nov.)	1959 (Feb.) completed 1960 (Feb.) commissioned
3. Hardware in Central Processor	2300 Vac. Tubes	4000 Vac. Tubes 13,000 Germanium Diodes	—	2700 Vac. Tubes 1700 Germanium Diodes 12,500 Resistors
4. Memory Type and Capacity	CRT (Williams Memory); 1024 words	CRT (Williams Memory); 2048 words	Ferrite core memory; 256 words	Ferrite core memory; 2048 words
5. Memory Cycle Time	—	12 μsec.	—	15 μsec.
6. Word Length	40 bits	36 bits	12 bits	40 bits
7. Logic Scheme	Parallel, asynchronous, fixed point, single address	Parallel, synchronous, fixed point, single address	Parallel, asynchronous, fixed point, single address	Parallel, asynchronous, fixed point, single address
8. Add/Subt. Time	60 μsec.	60 μsec.	—	45 μsec.
9. Multiply/Div. Time	800 (1100) μsec.	456 μsec.	—	500 μsec.
10. Input/Output	Punched cards, paper tape. A magnetic drum was added later	Punched cards, 150 lpm printer, magnetic tapes (100 bpi)	Paper tape, Teleprinter (page printer)	Paper tape, Teleprinter (page printer), CRT character display. A magnetic tape drive was added later
11. Total Power	—	88 kva.	10 kw.	20 kw.

computer technology had surged ahead, making TIFRAC an obsolete first generation machine. This, of course, was also true of the other Princeton-type machines which, however, by 1960, had had a useful life of about 5 years. None of these machines could have been updated into a second generation system by its original builders using the fabrication techniques they were accustomed to. This was because second generation computers required for their construction, in an essential way, production know-how and techniques which only large-scale computer manufacturers had or could command. This was the secret behind the sudden and dramatic improvements in the IBM systems within a short space of 5 years (1954-59). In view of this, the Institute, having decided in 1962-63 to upgrade the available computer potential, was wise to investigate in the world market for the best available commercially manufactured system.

Experience gained by using TIFRAC

TIFRAC was in operation from 1960 to early 1964, and towards the later part of this period, it was being operated for 2 shifts daily to cope with the computational demand on it. It would not be far wrong to say that many of the current computer users in India, handling highly sophisticated and advanced computational techniques, had their first introduction to programming through the use of TIFRAC. An important outcome of the TIFRAC project was the spread of computer consciousness among research scientists, primarily in TIFR, at the Bhabha Atomic Research Centre, Trombay, and some of the universities (notably the Crystallography Group of the Physics Department of the University of Madras). Data analysis of the early extensive air shower experiments of the cosmic ray group at TIFR would not have been feasible but for the availability of TIFRAC.

Once the construction of the main computer assembly was completed, more time was devoted to the development of peripheral hardware. A cathode ray tube display, with a novel character generation capability, was designed and built using a Memotron tube. There was a considerable amount of activity in the study of automata and coding theory and formal aspects of computation theory. Circuit design increasingly came to be based on the use of transistors. Using the same plug-in modules as in TIFRAC, a magnetic tape back-up storage for TIFRAC was developed and built.

On the programming side, the availability of a functioning computer made it possible to recruit and train additional programming staff members. A programming manual, as well as an extensive subroutine library, was built up to assist TIFRAC users. A 3-address interpretive routine for floating-point arithmetic, incorporating several features especially useful in matrix computations, was designed and implemented and proved to be very popular with the users.

The main and auxiliary storages of TIFRAC were too inadequate to attempt the development of compilers of any sort; so, programming had to be done essentially only at the level of the machine language.

The experience generated in maintaining and operating TIFRAC provided an invaluable opportunity to train and grow a group of technical personnel thoroughly conversant with the preventive maintenance aspects of a complex electronic system made up of hundreds of inter-connected sub-assemblies. The availability of all these trained personnel, with competence in hardware and software development and maintenance, proved to be of critical value subsequently when a decision was taken to go in for a commercially manufactured, large-scale second generation computer system.

Upgrading the computer facility

Between 1959 and 1962, some half-a-dozen of the scientists who had been actively concerned with the design and construction of TIFRAC had gone to various universities in the USA on a variety of visiting appointments. This availability in the USA of staff members of the Institute with specialized working knowledge of computers enabled TIFR to set up a Computer Committee of 4 persons to recommend for purchase by the Institute a large-scale digital computing system, taking into account the national requirements in this

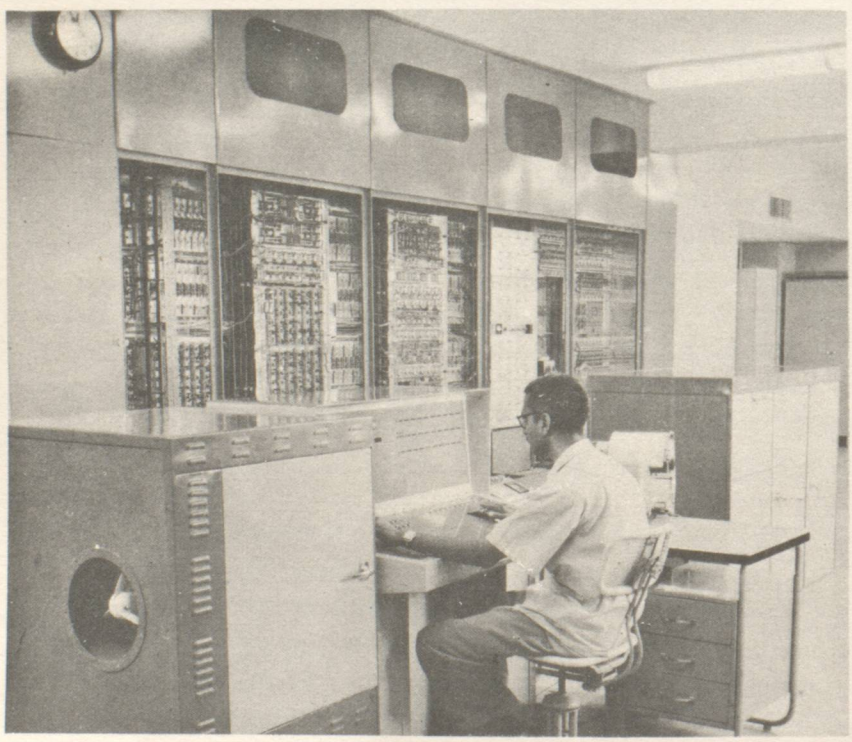


Fig. 3—TIFRAC in operation: TIFRAC was operational in 1959 and was used extensively between 1960-1964 by TIFR, BARC and a number of other government laboratories, educational institutions and private organisations.

field. This committee recommended in August 1962 the purchase by the Institute of a Control Data Corporation (CDC) 3600 system with a 160-A computer as a satellite. This recommendation was accepted by the Institute, and the system, with appropriate peripherals, was purchased with the assistance of a US AID loan. It was commissioned in Bombay during the middle of June 1964, to function as a national computational facility. The operational aspects of this Computer Centre are discussed separately elsewhere in this report.

Hardware activities

Research and development Activities subsequent to 1964

The OLDAP project. With the installation of the CDC 3600-160A system, hardware activity in the Computer Group had, by necessity, to become more specialized. It was, hence, decided late in 1965 to design and build an On-Line Data Processor (OLDAP) with very flexible real-time data-logging and control facilities. OLDAP was to be built with indigenous components to the maximum extent possible. The emphasis in design was not so much on speed, (since the use of available local transistors would preclude this anyhow), as on compactness, reliability, ease of maintenance, and such operational considerations. The specifications of OLDAP are summarised in Table II. The core-memory, the back-up drum storage, the paper-tape reader and punch, all forming part of the peripheral complex of OLDAP, were taken over from TIFRAC (which, in the meantime, had been disassembled).

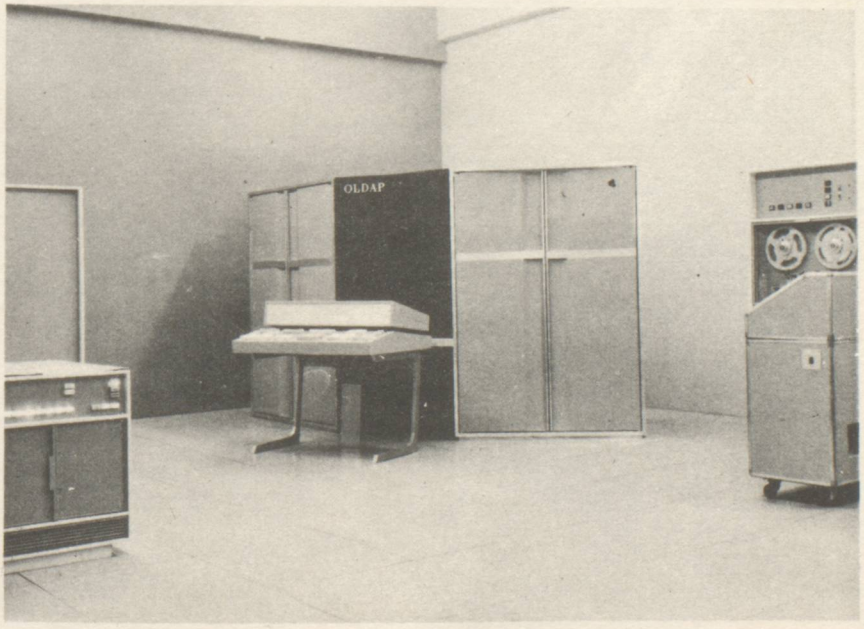


Fig. 4—OLDAP, an On-Line Data Processor, is a real time machine designed and built by the Computer Group of TIFR. Using mainly local components, and incorporating many novel features, the machine is intended to be used for data analysis in nuclear physics experimentation; currently it is being used for the bubble chamber film analysis work.

OLDAP has been set up as a central data-logging facility for use by experimental physicists of the Institute. The Bubble-Chamber Film Analysis Group is the primary user of this computer. They would use OLDAP as a preprocessor for their measurement data. Other experimental groups are also actively studying the possibility of exploiting the availability of OLDAP. The involvement of physicists in designing and building electronic interfaces to connect their own measuring equipment to OLDAP, should help to introduce modern data acquisition and analysis expertise in the physical sciences in the Institute.

Table II. Specifications of OLDAP System

OLDAP, an On-Line Data Processor, is a special purpose, fully transistorised digital, asynchronous machine. It has provision for 8 multiplexed analogue input data channels. The main features of the system are:

Word Length	. . . 12 bits
Fast Access Storage Capacity	. . . 8K expandable to 32K
Memory Cycle Time	. . . 6 microsecs.
Magnetic Drum Back-up	
Data Transfer Rate	. . . 9 microsecs./word
Average Access Time	. . . 10 millisecs.
Seven Hardware Registers each for which can interchangeably be used as an accumulator or an index register	
Basic Logic Module Speed	. . . 100 nanosecs.
Addition/Subtraction Time	. . . 7 microsecs. (including fetch)
Variable Length Instructions	
Addressing Modes	. . . Direct, indirect, double indirect, & double index modified
No. of Basic Instructions	. . . 88
Binary 2's Complement, Fixed Point, Arithmetic	
Built-in Multiply, Divide & Logical Operations	
Built-in Priority Interrupt System with 8 Interrupt Lines	

INPUT/OUTPUT

Analogue-to-Digital Converter: This acts as a real-time input device and can accept upto 8 multiplexed input channels at 200 microsecs. per channel.

Fast Paper Tape Reader (150 and 600 characters/sec.)

Fast Paper Tape Punch (300 characters/sec.)

Console Typewriter

Display console project. A second hardware project taken up was the construction of a visual display console with a light-pen facility to write on the display scope under on-line computer control. Such a console, with appropriate software support, could be used as a versatile tool in computer-aided design in architecture, machine drawing etc. This console is now operational and has been connected to the CDC 3600 computer. Some preliminary graphics packages have been developed for interactive work using this facility. It is proposed to use the display console in the design of printed-circuit art work.

Thin-film memory project. In connection with the design of OLDAP and the visual display console, a complete printed-circuit card fabrication facility was locally set up. The know-how and technical expertise involved in this effort extends all the way from precision art work and screen printing to flow-soldering and gold plating.

In 1967, a small pilot project was started to study the practicability of making thin magnetic film memories in the laboratory. Precision etching techniques were developed in collaboration with local industries. A complete memory assembly of 128 words of 24-bits has now been built and is being system-tested. The cycle time is in the range of 150-200 nS, but there is a possibility of non-destructive read-out. The memory module consists of 1000 A° permalloy films evaporated and etched on thin glass substrates and sandwiched between drive and sense lines etched from double-copper-clad, epoxy-glass laminates.

Fig. 5 & 6—The Light Pen Console: This interactive graphic display device is of great value in the utilisation of a high speed digital computer. The light pen console, designed and developed by the Computer Group of TIFR, is now connected to the CDC-3600 computer system.

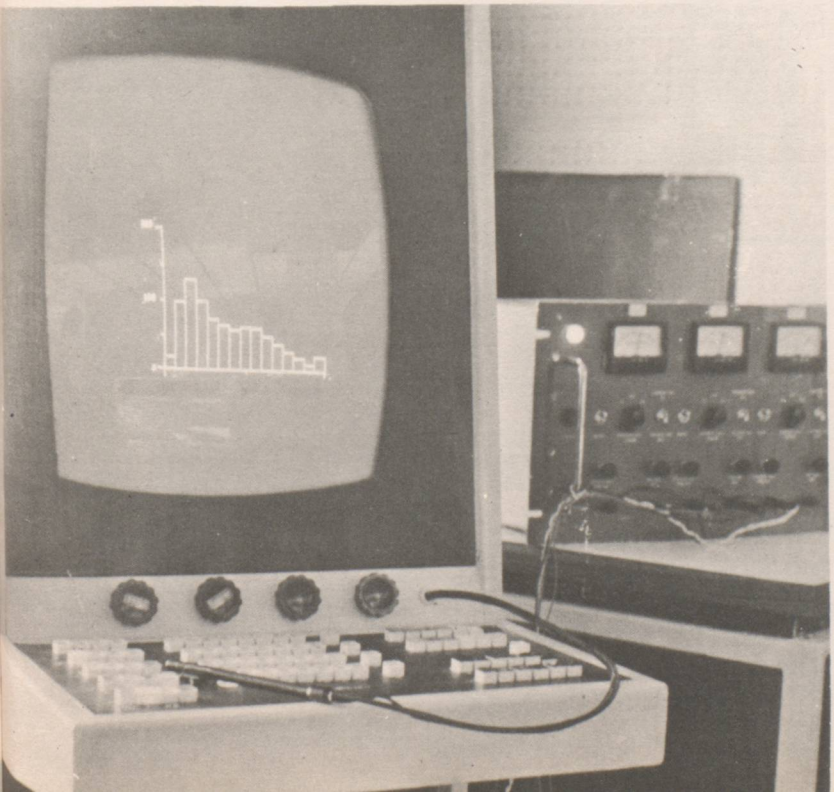


Fig. 6

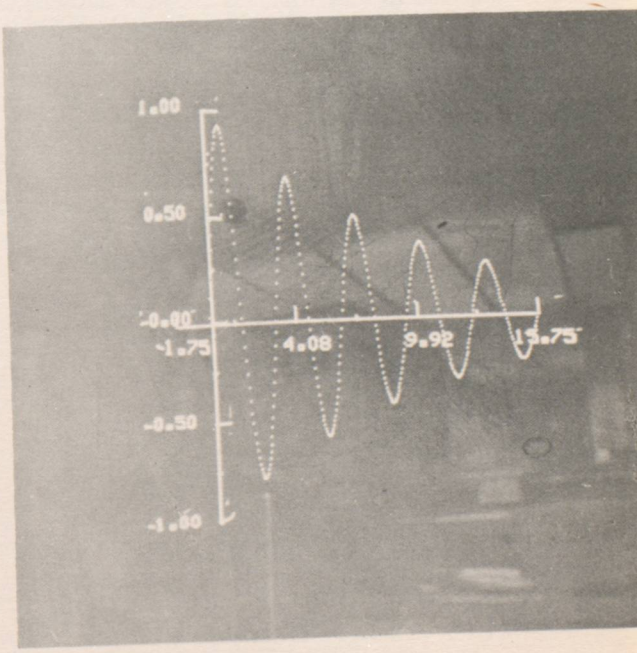


Fig. 5

Table III. A Summary of the Features of Large-Scale Computer Systems: Past, Present and Under Development

	Systems	Hardware	Software and Operation
1. First Generation 1945-1952	Small/medium systems consisting of a CPU* with about 1K words of CRT memory, paper tape or slow card reader input, drum backup storages of medium speed.	Vacuum tubes and germanium diodes; speed in the 50 μsec. range for addition; direct connection of peripherals to CPU.	Symbolic assembly language inputs; users operating the console on an open shop basis; direct interaction of user with CPU.
2. Transitional Stage 1953-1959	Large systems with high speed card readers, printers, magnetic tape secondary storages; ferrite core memory of over 32K words.	High speed switching transistors and diodes; speed in the 5-10 μsec. range for addition; time-sharing of central memory by CPU and peripherals through complex data interfaces.	Input programming through FORTRAN and first generation compilers.
3. Second Generation 1960-1965	Very large systems with a wide variety of very high speed peripherals.	Transistor-diode circuits on miniaturised printed circuit cards, solderless back-panel wiring; speed in the 1 μsec. range for addition; elaborate multiplexed data channels as I/O interfaces.	Complicated supervisors for optimized job shop operation; multiplicity of high level languages with sophisticated compilers; operation completely closed shop, thus, cutting off all direct interaction between CPU and the users.

Table III. (Contd.)

	Systems	Hardware	Software and Operation
4. Transitional Stage 1966-1970	Very large CPU's with multiprocessing capability; several remote-consoles connected to CPU in time-sharing mode; central core memory in the 65K range backed up by mass core storage of 100 to 200K words; conventional I/O's augmented by character readers, CRT displays with light pen, etc.; on-line data-logging facilities through preprocessing satellite computers.	Hybrid solid state circuits; thin film memory for specialised use; addition speeds in the 0.5 μsec. range.	Highly complicated supervisors for time-shared mode of operation along with job shop batch processing in the background; users interact again directly with CPU via remote consoles; complex displays and input facilities for on-line use.
5. Third Generation 1971-	Use of automatic scratch-pad memories; page-addressing of the main and backing memory; large solid-state main memory backed by mass core storage of 200 to 1000K. Extensive peripheral devices and remote processing stations. High speed pipe-lined CPU's for concurrent processing. Some automatic error-diagnosis with fault correction.	Completely integrated circuits; mass-array iterative logic; solid-state and plated-wire memories with speeds in the 100-200 nano-second range.	No new concepts but improved reliability of the system; fail-soft error handling through modular design. Small networks of computers for load-sharing. Some software produced by software generation systems.
	*CPU: Central Processing Unit.		

Integrated circuit packaging. The techniques used in the fabrication of a thin-film memory are precisely those needed for the packaging of integrated circuit (IC) modules into systems. A number of thin-film RC circuits with active elements externally bonded have been fabricated. Small digital systems like pulse generators, digital frequency meters, etc., have been developed using ICs.

Software and systems activities

Time-sharing system. In Table III are summarised some of the current trends in computer systems design and operation. From this table, it will be seen that three major features characterize these recent trends:

(i) There is an increasing tendency to get the users to interact directly with the central processors through remote time-shared consoles. There is also a tendency for these consoles to be provided with increasingly more sophisticated display and other on-line input/output facilities.
(ii) There is more and more, a tendency, to connect data-logging devices and other remote sensory and control equipment directly to large centralised processors through, where necessary, preprocessing satellite computers.
(iii) Discrete hardware is rapidly being replaced by hybrid and integrated circuitry.

Development activities in the Computer Group have been concerned with meaningful involvement in all these three aspects of current computer technology. The design and building of OLDAP and integrating it with the experimental physics programmes belong to aspect (ii) above. The involvement in IC technology has already been described.

The major software activity during the past two years has been concerned with building up an expertise in the design, implementation and use of time-sharing systems (aspect (i) above). TOPS (Time-sharing Operating System) has been designed to provide a time-sharing facility on the CDC 3600-160A system, using a large capacity disc file. It is designed to allow editing of files and program debugging (testing) using remote typewriter terminals, concurrent with the normal batch processing of jobs. Users are allowed to maintain files on the disc which may be accessed either from remote terminals or from running programs. It is expected that this facility will provide an environment for rapid program testing.

Computer-aided graphics. During the past few months, an effort has been made to develop computer programs for drafting. In the fabrication of IC masks, it is very important to prepare accurate layouts of the device or circuit

geometry on a plane surface. Computer-aided preparation of such layouts is increasingly coming into vogue. The Calcomp plotters in the Computer Centre are made use of in this graphics project.

Development of IC computer systems. The trends outlined in Table III relate primarily to the design of large-scale, general-purpose computer systems. There has also been a parallel trend in the last few years in the development of small computers. With the commercial viability of the solid state electronics technology, the hardware cost of the central processing unit (CPU) has been coming down dramatically. This has made it possible for relatively small manufacturing concerns to develop and market mini-computers (such as programmable desk-calculators) and small word-size (e.g., 8, 12 and 16-bits) computers for a variety of special applications.

The Electronic Corporation of India Ltd. (ECIL), a manufacturing unit of the Department of Atomic Energy, has already started marketing a small computer (with a word-size of 12-bits) completely locally designed and produced. ECIL plans to develop and market 16- and 32-bit IC computers. The Computer Group will have a major responsibility in the development of these computer systems along with ECIL.

Simulation and modelling

The availability of a large, high-speed digital computer, such as the CDC 3600, makes it possible to undertake research in the development of information processing models of various kinds, by simulating them on the computer using appropriate software. Some of the activities of this nature currently being pursued are described below.

Modelling perceptual behaviour. From the view point of fundamental research, the information processing models of the greatest significance are those concerned with human sensory perception. Of these human faculties, by far the most complex and the most highly developed are visual perception, and speech (generation and perception). The development of computer models capable of imitating these human perceptual activities is one of the most active and exciting areas of current research.

Models for the generation, analysis, and description of pictures have been studied through the use of specially developed programming languages. As an outcome of this work, computer animation techniques have been developed for generating dynamic visual displays using the 3600 computer. A handprinted letter generator and recognizer have been developed.

A very flexible speech synthesis programme has been developed for the 3600 system. It accepts typewritten input in phonetic alphabet from the console, synthesizes the specified speech fragment, and plays it back. Since this method of speech synthesis is intrinsically universal, speech in all languages can be synthesized using this program. An effort is underway to augment this program, to transform printed text into speech taking into account prosodic features such as stress and intonation. Some preliminary work is also being done on the recognition of speech.

The availability of the speech synthesis package has made it possible to engage in several speech perception experiments. Specifically, experiments concerned with determining weightages of individual acoustic cues for perception, effects of coarticulation, and the relation between articulatory and perceptual phonemic boundaries (in the frequency-energy-time space) have been initiated.

Modelling language behaviour. Visual perception and speech generation are only the peripheral aspects of the most central intellectual capacity of human beings, which is the capacity to acquire and use a variety of languages. The development of computer programs that imitate human language behaviour is a profoundly complicated task. Much of the complication consists in being able to precisely articulate questions such as: What is a language? Of what does language competence consist? What are the minimal requirements of an interactive environment to learn and use a language? And other similar fundamental issues.

Some preliminary work has been done to formulate a framework to cope with some of these questions. Within this framework, a theory of computational languages has been developed. Some tentative work has also been done to enlarge this framework to deal with natural language behaviour. As part of a doctoral thesis effort, a program has been written to model language-based problem-solving capability.

Operations research and systems science

The availability of large-scale computers has introduced radical changes in engineering systems design and management techniques. Basic and applied research in both these areas have been the concern of some of the scientists of the Computer Group.

An optimized bus scheduling program was developed for the BEST Bus Transport Service in Bombay city. An optimal design of the electrical distribution system of the BEST Electricity Supply Service was also carried out. This has now been implemented over almost the whole of Bombay city. A major effort was concerned with the optimization of the mix of thermal, hydel, and nuclear power station in the Northern Region of India. This project was carried out in collaboration with the Department of Atomic Energy, and the concerned

state Electricity Board engineers. Another major effort was concerned with the development of simulation and optimization packages for the design of multi-stage satellite launch vehicles involving three-dimensional, six-degree of freedom, controlled, atmospheric flights. An integrated optimization program for the design of nuclear reactors is also being developed.

Basic research in Systems Science has so far resulted in three new concepts: Hypercorrelation, Vectorial Flowgraphs, and Field-embedded Graphs. Hypercorrelation has proved to be useful in the design of optimal spatial layouts. Vectorial Flowgraph has been found to be a valuable concept in the analysis of large-scale feedback systems such as a mixed economic system. The growth of Research and Development activity has been characterized using concepts from graph theory and algorithms for optimal resource allocation have been worked out.

Much of the administrative data processing within TIFR has been computerized progressively. Some years ago, the salary bill preparation was completely automated. Next, all the stores procedures were computerized. This has now made it possible to attempt computerized inventory control of the TIFR stores. Finally, the entire purchase and budget control procedures have been computerized. In doing this, care has been taken to integrate the purchase, stores and budget control aspects.

Other Research Areas

Research is also being conducted in the area of formal theory of computation, in many-valued logic, in linear and non-linear programming, and in numerical solutions of boundary-value problems in fluid flow. Continuing research projects do not exist in these problem-areas and research goals are essentially determined by the immediate interests of individual scientists.

Medical electronics

An application area with vast untapped potentials is medical electronics. Work in this area could be meaningfully carried out only in cooperation with working medical personnel in the country. A small beginning has been made by way of a collaborative project with a Bombay hospital. An energy monitor, an instrument developed by the Computer Group for the analysis of human EEG signals, is being field-tested in this hospital. Preliminary trials have confirmed that this instrument is an improvement over existing methods for the diagnosis of Schizophrenia. Its use in studies on epilepsy is currently under investigation.

The National Computation Centre

Background

In July 1962, the Tata Institute of Fundamental Research decided to upgrade its inhouse computational capability (which then consisted of the TIFRAC computer designed and built at the Institute) by installing a large-scale second generation computer system. Accordingly it set up a Computer Committee consisting of 4 of its staff members, all in the USA at that time, with the following terms of reference: "...to recommend for purchase by the Institute a large-scale computer system... to make an assessment of available computers taking into account the national requirements in this field... to visit the production centres, meet the persons who have designed the machines, see the operations of the computers at existing installations, and meet their technical personnel for discussions ... the computer the Institute is to purchase will be of the level of an IBM 7090...".

The Committee accordingly spent 6 weeks discussing with IBM, Control Data Corporation (CDC), Univac and Philco representatives and their production personnel in New York, Philadelphia, and Minneapolis. Their final recommendation was submitted in August 1962, suggesting the purchase by the Institute of a CDC 3600 computer with a 160-A as a satellite. This recommendation was made after analysing in detail the technical and performance characteristics, and cost structures of 4 computer systems, viz., IBM 7094, CDC 3600, Philco 211, and Univac 1107. The fact that several Atomic Energy Laboratories and Universities in the USA were actively considering installing CDC 3600 systems provided additional assurance of the basic soundness of the recommendation.

Commissioning the computer system

TIFR accepted the recommendation and started negotiations with CDC for the purchase of a 3600-160A system with a card reader and punch, paper tape reader and punch, 10 magnetic tape units, and one high speed and one low speed line printer. It took 20 months for the formalities to be completed and for the actual delivery of the computer system. With the help of a US AID loan, the entire system was purchased and commissioned in Bombay during the middle of June 1964, to function as a national computational facility.

The waiting period was effectively used in training maintenance engineers and system programmers to take charge of the computer system after installation, and in getting the site ready in TIFR to receive the system on arrival for installation.



Fig. 7—The CDC-3600-160A Computer system, one of the fastest and most versatile machines of its time, was acquired by TIFR to serve the growing needs of the Institute and other users in the country. The photograph shows one of the large racks of the system being unloaded (May 1964) from the chartered aircraft which brought the system in.

5 maintenance engineers and 3 programmers were sent to Minneapolis for periods varying from 6 to 9 months to be trained by CDC. The availability of senior scientists from TIFR in the USA during the period helped considerably in coordinating all these training programmes and ensuring that the maximum relevant know-how was transferred during the limited period of stay.

The effectiveness of all this preparatory work is, perhaps, best summed up by the following factual details. The entire CDC system reached Bombay by air on May 10, 1964. CDC installation personnel started work the next day and power was switched on, on May 18, 1964. On June 16, 1964, the computer was declared ready for acceptance and the acceptance letter was handed over. There were some initial troubles with the supervisor program. But these were effectively ironed out, and on July 10, 1964, the first user's job was run successfully. From September 1964, the complete maintenance was taken over by TIFR engineers. From October 1964, the National Computation Centre started functioning as a regular facility.

Operational experience with the system

As described earlier, 5 engineers from TIFR were deputed to Minneapolis to be trained by CDC in maintaining the 3600-160A computer system. They were present at CDC during the various phases in the assembly and check-out of the actual computer system which was then shipped to Bombay. These engineer took charge of the system in September 1964. For one year, till September 1965, CDC made available 2 of their own customer engineers in Bombay to train a second batch of 5 Indian engineers using the TIFR computer system. The two CDC engineers were also available to assist in maintenance on call should such a need arise. These were the terms of a technical support contract agreed upon for one year between TIFR and CDC.

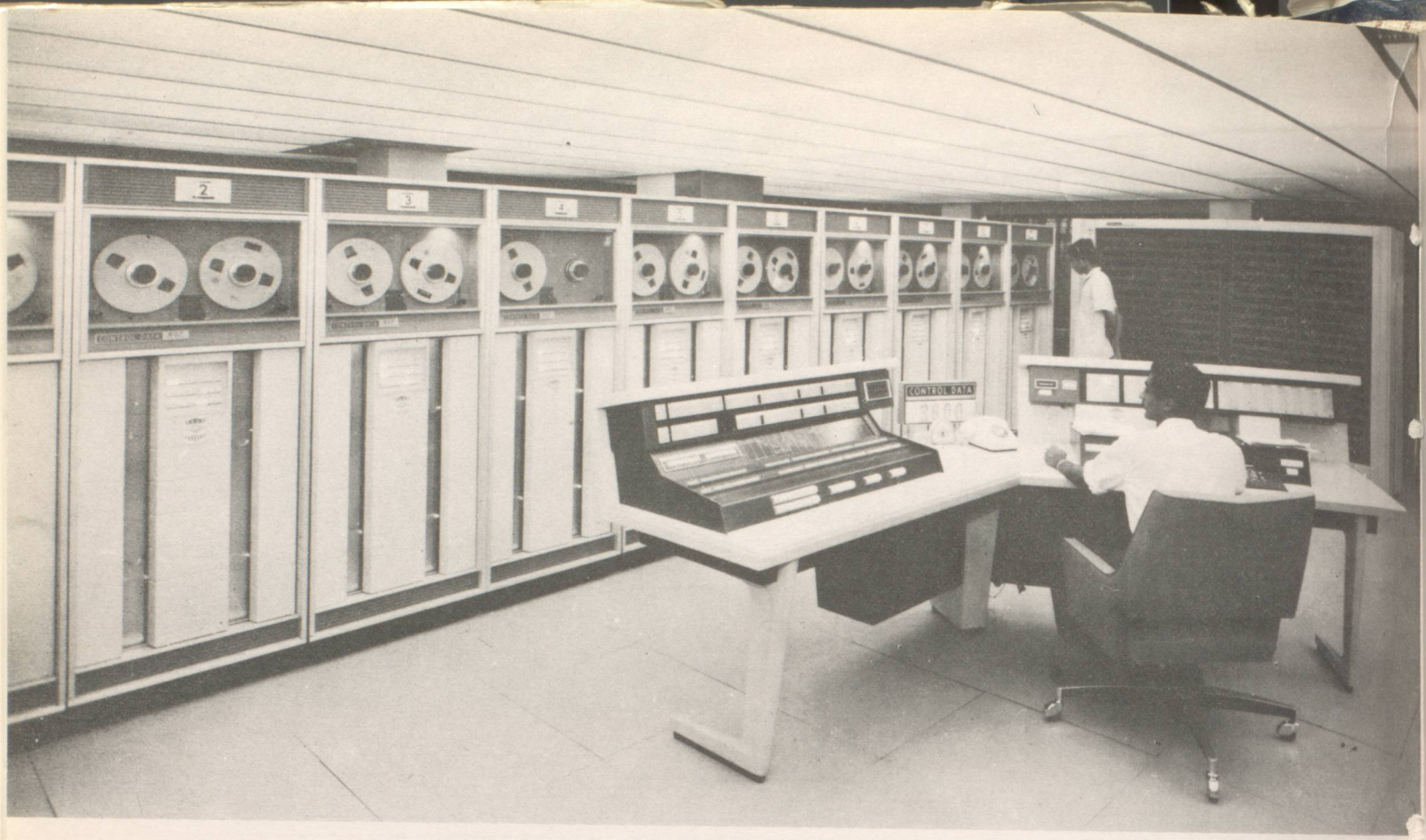


Fig. 8 — The CDC-3600-160A installation is being operated by the Institute as a national facility. It is currently used by over a hundred educational, industrial and government organisations in the country. The system is maintained and operated by trained TIFR staff. It is now being operated 24 hours each day for all days of the week including Sundays and holidays. It is now planned to acquire a much larger machine to meet the future needs.

The up-time of the total system has been consistently above 98% except on two occasions of major breakdown, once with a data channel, and the second time, when one of the memory drive lines got burnt. In the later case, which was a catastrophic failure, although the CDC ruled out any possibility of repairing the memory stack on site, our own engineers were able to redeem the situation by suitably altering the drive logic. This enabled the computer to be put back into operation in less than 24 hours, although with its storage capacity reduced by 128 locations.

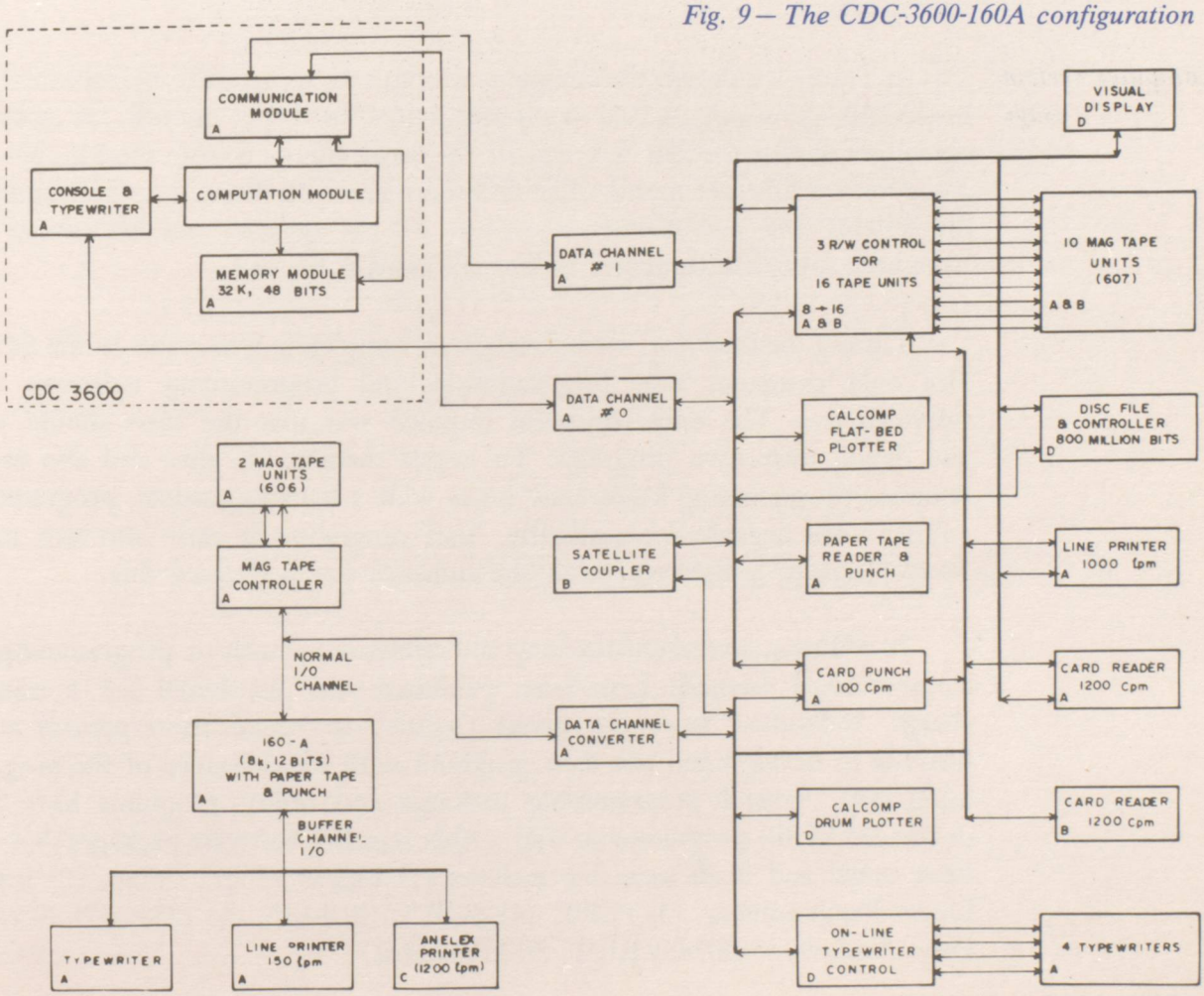
Most of the logic failures are usually isolated by means of test programs. Such failures normally show up and are rectified during daily preventive maintenance, which is carried out for about 2 to 2½ hours each morning. Most of the software diagnostic routines for this purpose have been supplied by CDC. Some further specialized routines have been locally developed by TIFR engineers.

Apart from electronic troubles, there have also been several mechanical failures with the peripherals. On several occasions, mechanical replacement parts have been fabricated in the TIFR workshop and used successfully.

On the whole, our hardware maintenance experience over the last 5 years has conclusively confirmed the essential wisdom of the original decision to take on the maintenance responsibility on our own. Not only has this experience proved beneficial in terms of building up confidence, know-how and experience, but monetarily, TIFR has gained significantly. CDC normally charge $.2,76,000 per year for the maintenance of a computer configuration such as the one at TIFR. Out of this, they claim, they use replacement parts worth $.1,13,000. As against this, the average annual cost of spares used actually by TIFR amounts only to $.8,500 out of which roughly $.1,200 is for printer ribbons which are really stationery items. It has been possible to keep down the cost of maintenance to this low figure by making every attempt to repair all the electronic cards and electro-mechanical sub-assemblies and re-using them.

The development, updating and maintenance of software have been completely the responsibility of the TIFR programming staff right from the beginning. The Computer Centre maintains a large and reasonably complete program library for the users. A comprehensive Service PACK age (SPACK) was locally developed to use the 160A off-line for input-output processing. Apart from the standard input-output, SPACK produces an abstract of the accounting tape on cards which are subsequently processed to compute charges for users on a monthly basis.

Fig. 9 — The CDC-3600-160A configuration



A 1964
B 1965
C 1968
D 1969

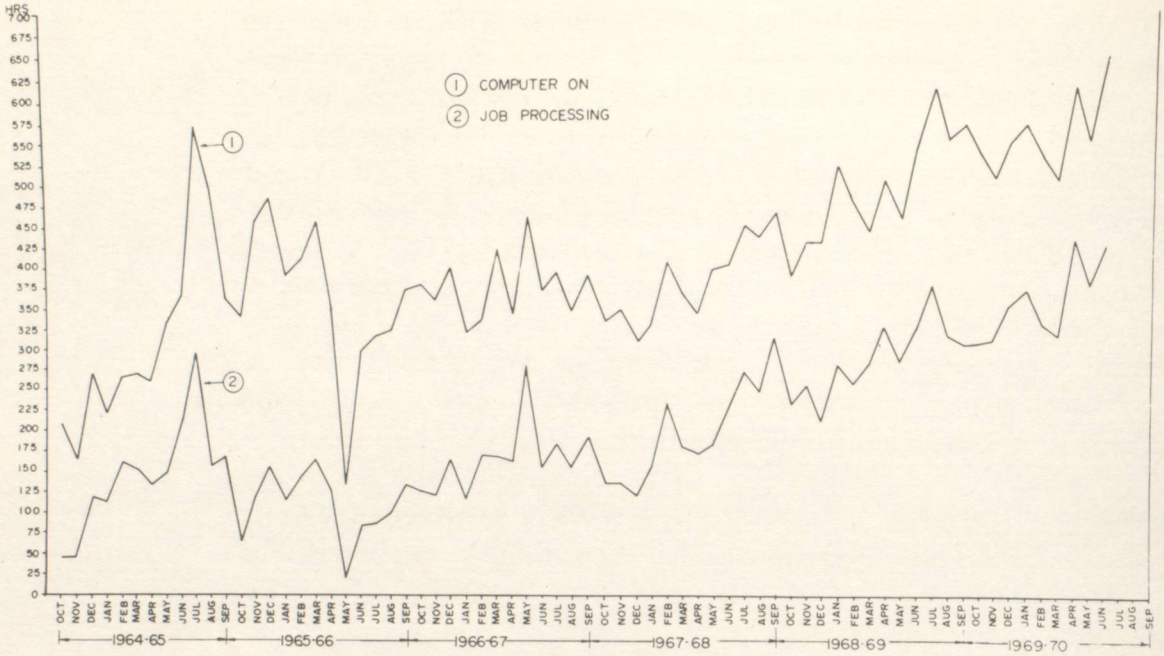


Fig. 10—Monthly computer usage for job processing

Computer system usage

In Figure 9 is shown the computer configuration currently available at TIFR. Figure 10 shows the actual computer hours used per month for job-shop operation during the last 5 years. In the same figure is also shown the total computer-on time per month. The difference between the two graphs represents the systems time and maintenance time. All the agencies and institutions that have been using the computer facility are listed at the end.

During the first year, users were given completely free access to the facility. Not only computer time but stationery and programming assistance were provided free. The only constraint imposed was that the users should write and debug their own programs. To enable them to do this, and also to disseminate programming know-how on as wide a basis as possible, programming courses were organized periodically. Staff programmers were also sent to the users' places to lecture whenever the audience size warranted this.

In addition, several self-teaching and reference manuals on programming and computational methods have been published and distributed for a nominal charge. Individual users are given facilities to spend short periods at the Institute to develop and test their programs with the assistance of the programming staff. Several programming packages and utility programs have been developed by the programming staff. Other standard software packages that have been tested and made available include: (1) Linear Programming, (2) Integer Linear Programming, (3) PERT, (4) SORT, (5) SLIP, (6) LISP, (7) Network Flow Analysis, (8) SIMSCRIPT, (9) DYNAMO.

From October 1965, it was decided to charge the users for computer time actually used by them. This charge was fixed as Rs.8/- (=$.1.07) per minute of CDC 3600 time used. From October 1967, the charging procedure was again modified so as to include, on the basis of actual cost, the stationery consumption also. The entire housekeeping associated with job processing and accounting for computer usage is automatically handled by means of a specially developed accounting program. This program has been designed to generate a variety of auxiliary information about the usage of the computer system.

In 1969, the computer system was upgraded with the addition of a 16.778 million word disc-file, and two CALCOMP plotters. Using the disc-file as the main bulk storage a limited time-sharing system with 8 typewriter consoles is being implemented. A visual display console with read/write facility has been locally designed and connected to the 3600 system. This console can be used for the development and use of interactive graphics software.

Currently, the computer system is operational 24 hours/day, seven days a week including Sundays and holidays.

LIST OF USERS OF THE CDC 3600-160A COMPUTER SYSTEM

1. Tata Institute of Fundamental Research, Colaba, Bombay.
2. Bhabha Atomic Research Centre, Trombay, Bombay.

Department of Atomic Energy; Others

3. Department of Atomic Energy, Bombay.
4. Experimental Satellite Communication Earth Station, Ahmedabad.
5. Indian Cancer Research Centre, Bombay.
6. Physical Research Laboratory, Ahmedabad.
7. Saha Institute of Nuclear Physics, Calcutta.
8. Space Science and Technology Centre, Thumba, Trivandrum.
9. Tarapur Atomic Power Project, Bombay.

Institutes of Technology and Engineering

10. Birla Institute of Technology and Science, Pilani, Rajasthan.
11. College of Engineering, Ahmedabad.
12. College of Engineering, Poona.
13. College of Military Engineering, Poona.
14. Government Engineering College, Jabalpur.
15. Govindram Seksaria Technical Institute, Indore.
16. Indian Institute of Science, Bangalore.
17. Indian Institute of Technology, Powai, Bombay.
18. Indian Institute of Technology, Kharagpur.
19. Indian Institute of Technology, Madras.
20. Indian Institute of Technology, New Delhi.
21. Institute of Mathematical Sciences, Madras.
22. Institute of Science, Bombay.
23. Maulana Azad College of Technology, Bhopal.
24. Sardar Patel College of Engineering, Bombay.
25. Structural Engineering Research Centre, Roorkee.
26. Victoria Jubilee Technical Institute, Bombay.

Universities, Science Colleges, etc.

27. Agra College, Agra.
28. All India Institute of Medical Sciences, New Delhi.
29. Andhra University, Waltair.
30. Astro Physical Laboratory, Kodaikanal.
31. Bajaj Institute of Management Studies, Bombay.
32. Banaras Hindu University, Varanasi.

33. Bangalore University, Bangalore.
34. Bombay University, Bombay.
35. Calcutta University, Calcutta.
36. Deccan College, Poona.
37. Delhi University, Delhi.
38. Demographic Training and Research Centre, Bombay.
39. Gujarat Research Society, Bombay.
40. Haffkine Institute, Bombay.
41. Indian Institute of Management, Ahmedabad.
42. Jadavpur University, Calcutta.
43. Jaipur University, Jaipur.
44. Karnatak University, Dharwar.
45. Madras University, Guindy, Madras.
46. Presidency College, Calcutta.
47. Rajasthan University, Jaipur.
48. Ranchi University, Ranchi.
49. Shivaji University, Kolhapur.
50. SNDT Women's University, Bombay.
51. St. Joseph's College, Tiruchirappalli.
52. Summer Institute of Linguistics, Poona.
53. University of Mysore, Mysore.
54. University of Poona, Poona.
55. University of Roorkee, Roorkee.
56. Visvesvaraya Regional College of Engineering, Nagpur.

CSIR Laboratories

57. Central Electronics Engineering Research Institute, Pilani, Rajasthan.
58. Central Electrochemical Research Institute, Karaikudi.
59. National Aeronautical Laboratory, Bangalore.
60. National Chemical Laboratory, Poona.

Other Government and Quasi-Government Organizations

61. Bombay Municipal Corporation, Bombay.
62. Central Design Organization, Bombay.
63. Central Water and Power Research Station, Poona.
64. Colaba and Alibagh Observatories, Bombay.
65. Cotton Textile Export Promotion Council, Bombay.
66. Director General of Observatories, Poona.
67. Fertilizer Corporation of India Ltd., Trombay, Bombay.
68. Geological Survey of India, Calcutta.
69. Government Dental College and Hospital, Bombay.
70. Heavy Electricals (India) Ltd., Bombay.
71. Income-Tax Department, Bombay.
72. Indian Association for the Cultivation of Science, Calcutta.

73. Indian Statistical Institute, New Delhi.
74. Institute of Tropical Meteorology, Poona.
75. Maharashtra Engineering Research Institute, Nasik.
76. Maharashtra State Electricity Board, Bombay.
77. Mazagon Docks Ltd., Bombay.
78. Ministry of Food and Agriculture, New Delhi.
79. Rajasthan Can Soil Investigation Project, Bikaner.
80. Reserve Bank of India, Bombay.
81. The State Industrial and Investment Corporation, Bombay.

Private Sector and Miscellaneous

82. Air-India, Bombay.
83. Associated Cement Companies Ltd., Bombay.
84. Bhagat Engineering Co. Ltd., Bombay.
85. Bhalla, K.C., Bombay.
86. Bharat Bijlee Ltd., Bombay.
87. Bhirud, M.L., Bombay.
88. Bombay Electric Supply and Transport Undertaking, Bombay.
89. Bombay Metal and Alloys Mfg. Co. Pvt. Ltd., Bombay.
90. Bombay Textile Research Association, Bombay.
91. Builders Associates, Bombay.
92. Burmah-Shell Oil Storage and Distributing Co., Bombay.
93. Century Rayon, Bombay.
94. Computech Corporation, Bombay.
95. Computer Technology Institute, Bombay.
96. Datamatics Corporation, Bombay.
97. Design EDP Consultants, Bombay.
98. Devidayal Stainless Steel, Bombay.
99. Duban Engineering Co., Bombay.
100. Dynacraft Machine Co. Pvt. Ltd., Bombay.
101. Engineering Services, Bombay.
102. Engineers India Ltd., Bombay.
103. Environmental Engineering Consultants, Bombay.
104. Family Planning Association of India, Bombay.
105. Fatehi, T.T., Bombay.
106. Gherzi Eastern, Bombay.
107. Godrej Soaps Pvt. Ltd., Bombay.
108. Goodwill Entrepreneurs, Bombay.
109. Gupta, S.M., Bombay.
110. Herle, U.S., Bombay.
111. Hindustan Lever Ltd., Bombay.
112. Indian Cancer Society, Bombay.
113. Jal N. Bharucha, Bombay.
114. Jyoti Ltd., Bombay.
115. Kamani Engineering, Bombay.
116. Krishnan, S., Bombay.

117. Larsen and Toubro Ltd., Bombay.
118. Lawkim Ltd., Thana.
119. Mafatlal Services Pvt. Ltd., Bombay.
120. May and Baker Ltd., Bombay.
121. Mirex Heat Transfer Pvt. Ltd., Bombay.
122. Mukand Iron and Steel Works Ltd., Bombay.
123. National Organic Chemical Industries Ltd., Thana.
124. Nayak, R.M., Bombay.
125. New Standard Engineering Co. Ltd., Bombay.
126. Oak, A.D., Poona.
127. Oil India Ltd., Assam.
128. Operations Research Group, Bombay.
129. Panama Pvt. Ltd., Thana.
130. Patel, S.B., Bombay.
131. Pathare, P.R., Bombay.
132. Patki and Dadarkar Engineering Services, Bombay.
133. Rajabahadur Mills Ltd., Poona.
134. Ralliwolf Ltd., Bombay.
135. Research and Marketing Services, Bombay.
136. R.G. Joshi and Associates, Poona.
137. Richardson Hindustan Ltd., Bombay.
138. Road Development and Designs Division, Bombay.
139. Rocket Engineering Corporation Ltd., Kolhapur.
140. Roy, S.K., Poona.
141. Sandoz India Ltd., Bombay.
142. Sethna, H.K., Bombay.
143. Silk and Art Silk Research Association, Bombay.
144. STAT Services, Bombay.
145. Synthetic Moulders Ltd., Bombay.
146. Stock Exchange, Bombay.
147. Tata Chemicals Ltd., Bombay.
148. Tata Consultancy Services, Bombay.
149. Tata Engineering and Locomotive Co., Ltd., Poona.
150. Tata Hydro Electric Co., Bombay.
151. The Indian Hume Pipes Co. Ltd., Bombay.
152. The Systems, Bombay.
153. Ultra Industries, Bombay.
154. Voltas Ltd., Bombay.
155. Water Supply Specialists, Bombay.
156. Dental Research Project, TIFR, Bombay.
157. US AID, American Embassy, New Delhi.

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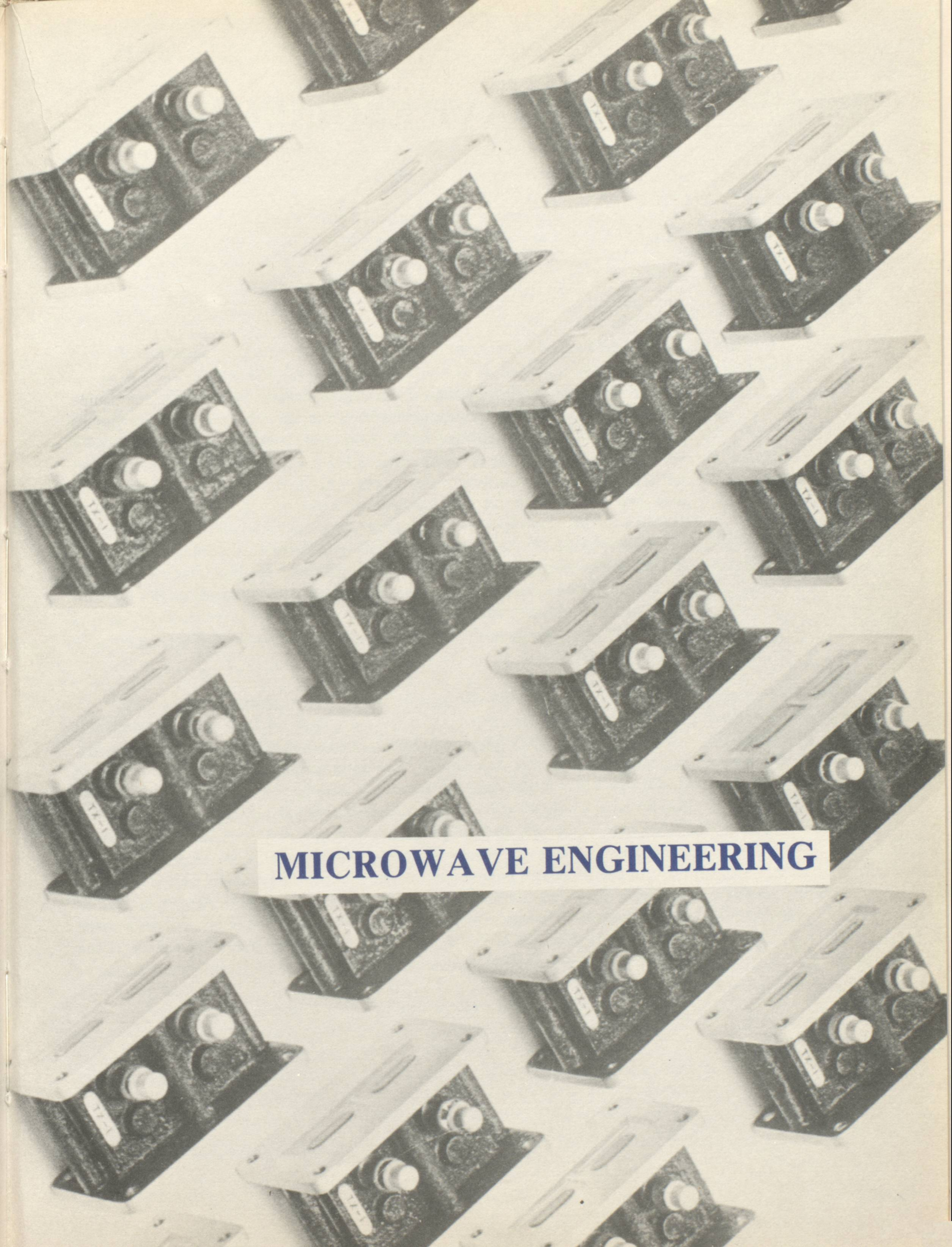
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MICROWAVE ENGINEERING

MICROWAVE ENGINEERING

Development and fabrication of specialised devices, instruments and equipments for research and applications has been one of the important activities in the Institute from its inception. In the early years participating in this activity were not only staff members of the Institute but also staff of the DAE/AEET/BARC located at the Institute under a common discipline. While research needs provided the stimulus for development of many experimental techniques, it turned out that the full potential of these advances could be readily utilised to form the nucleus for the technical production facilities needed by the DAE/BARC in the earlier stages (upto the sixties). After the Bhabha Committee report on Electronics and the formation of the Electronics Commission of the Government of India, the expertise developed in a variety of experimental techniques and nuclear instrumentation, enabled the application of these for diverse nationally important purposes.

Particle Detectors

In the early days Giger Muller Counters were extensively used in the Institute's cosmic ray experiments for telescopes, hodoscopes and triggered cloud chambers. Developmental work initiated in this connection led to the development of highly reliable, low cost sensitive radiation detectors used in the early phase of atomic energy programme. Associated with this development grew the techniques for sealed off vacuum devices, and the understanding of intricate gas discharge phenomena. Large number of counters had to be made for alpha, beta, gamma and cosmic ray measurements. Counters operating at low voltage using halogen quenching were developed for use in portable radiation monitors. Based on all this knowhow, the ECIL started producing these G.M. Counters for the consolidated requirements of the country in the latter years.

An array of Batch produced TR tubes.

Electronic Nuclear Instrumentation

The activity consisted of development of the instruments for observation and counting of particles in the cosmic ray and nuclear experiments. The instruments developed were pulse amplifiers, shapers, coincidence circuits, ratemeters, multichannel analysers, high voltage supplies, portable radiation survey meters for radioactive mineral prospecting, cathode ray oscilloscopes, scintillation counting devices etc. These instruments were developed and produced as professional grade equipments. This activity moved out in the late fifties to AEET/ BARC and then to ECIL.

Plasma Physics Experiments

Two installations were set up for high energy plasma studies. One of these consisted of containing the plasma of deuterons with electric and magnetic fields, operating at 20 KV and 100 mA with facility to monitor the neutron production. The other setup consisted of a torous discharge having 1 metre dia, and a 5 cm i.d. torous tubes. A number of pulsing, triggering and monitoring devices and circuits have been made for this equipment.

Particle Accelerators

The activity in the Institute on particle accelerators was essentially that of establishing technological feasibility to design and fabricate particle accelerators based on different principles, namely cyclotrons, Van de Graaff, linear accelerators etc.

Work on Cyclotron and Van de Graaff Generators

This work was carried out mainly during the fifties, in the nature of a feasibility study to lead to high energy cyclotrons. A one million volt proton cyclotron with a 100 ua beam current was set up using a 30 cm magnet. A feasibility study for the construction of a strong focussing synchrotron was also made. A 500 KeV Van de Graaff accelerator was set up indigenously, which had a charge transport of 1 mA current with 45 cm belts.

Electron Linear Accelerators

Work on the development and construction of an Electron Linac was taken up in the later part of the fifties and the accelerator was fabricated and put into operation by 1960. Additional features were incorporated subsequently. This is an example of how pursuit of building a high technology equipment for particle physics studies, led to many other applications of the equipment and to exploitation of the involved technologies for applied purposes. The accelerator used a pulsed two megawatt microwave radiation to accelerate electrons in a slow travelling wave structure to an energy of 3.5 MeV. The dimensional accuracy of the slow wave structure, the close frequency tolerance for resonance acceleration, the high microwave powers and fields involved, the electron beam dynamics, high vacuum, heat transport are stringent requirements met by the technology developed for the purpose. The major components, circuits and systems for the

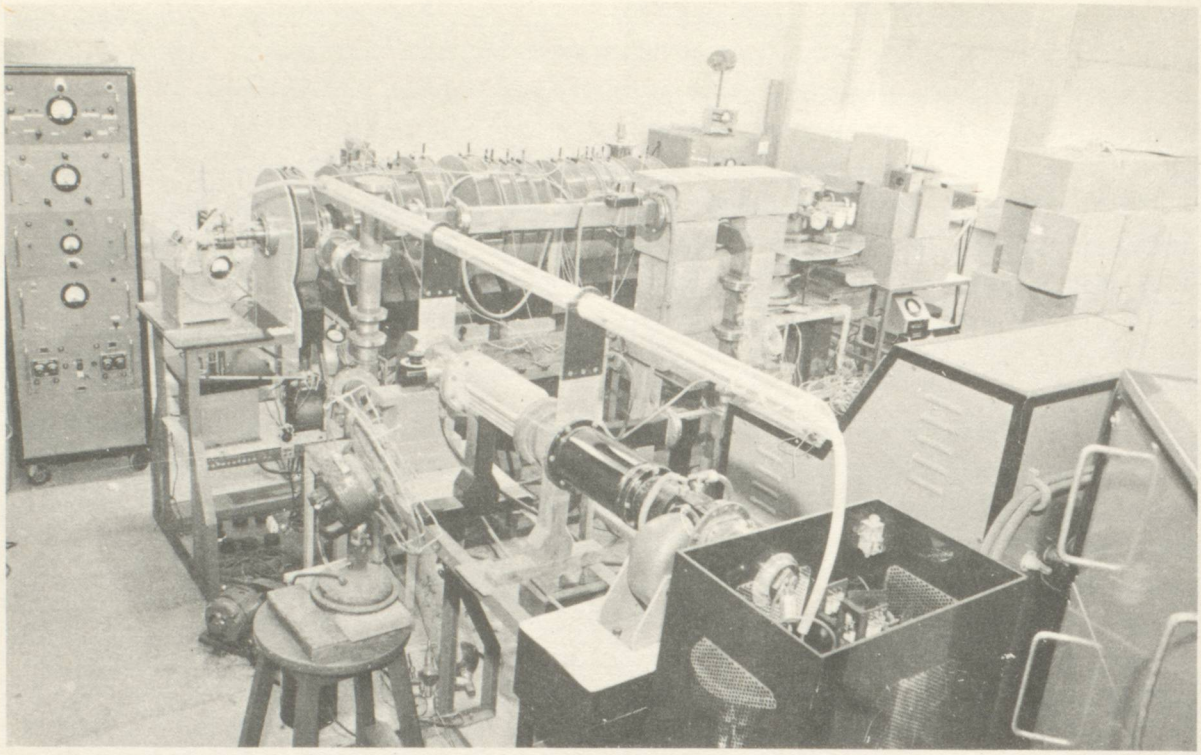


Fig. 1—Electron Linear Accelerator.

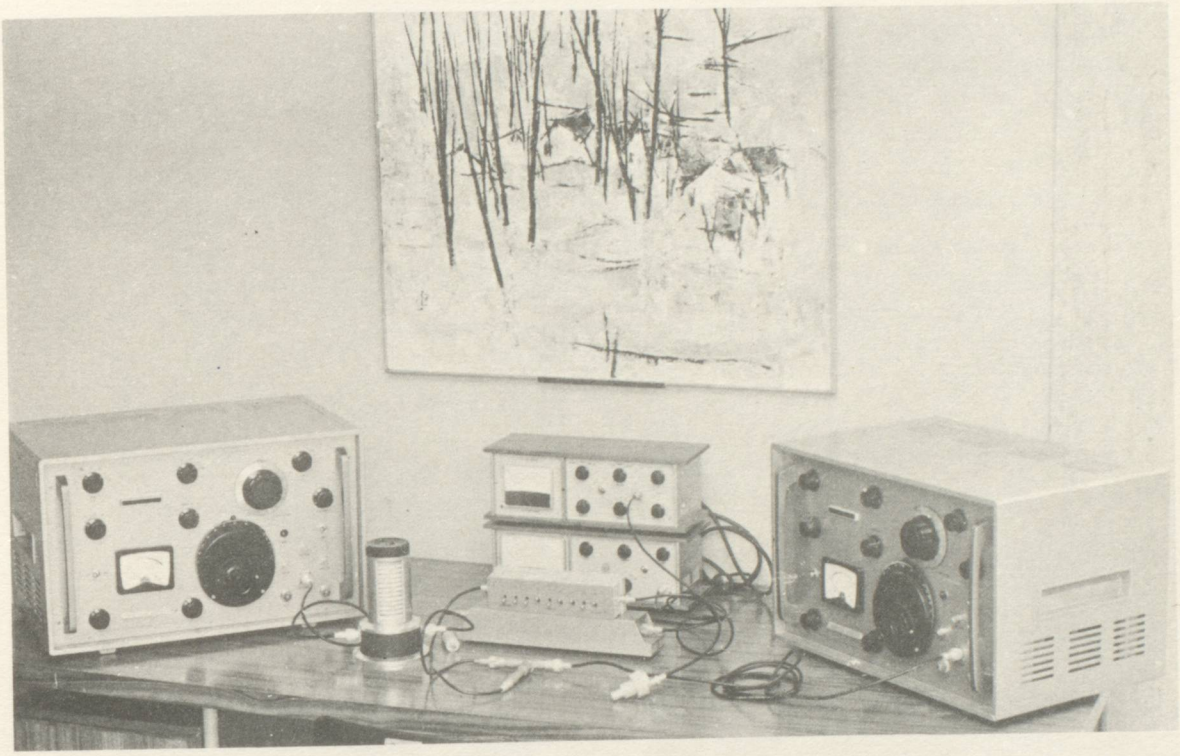
accelerator were built in the Institute. The technology is directly applicable not only to fabrication of industrial and medical accelerators but also to development of microwave power tubes and components for modern radar and communications. The accelerator is being used as an irradiation facility employing its electron beam (20 ma, 1.5 microseconds, 100 p.p.s.)

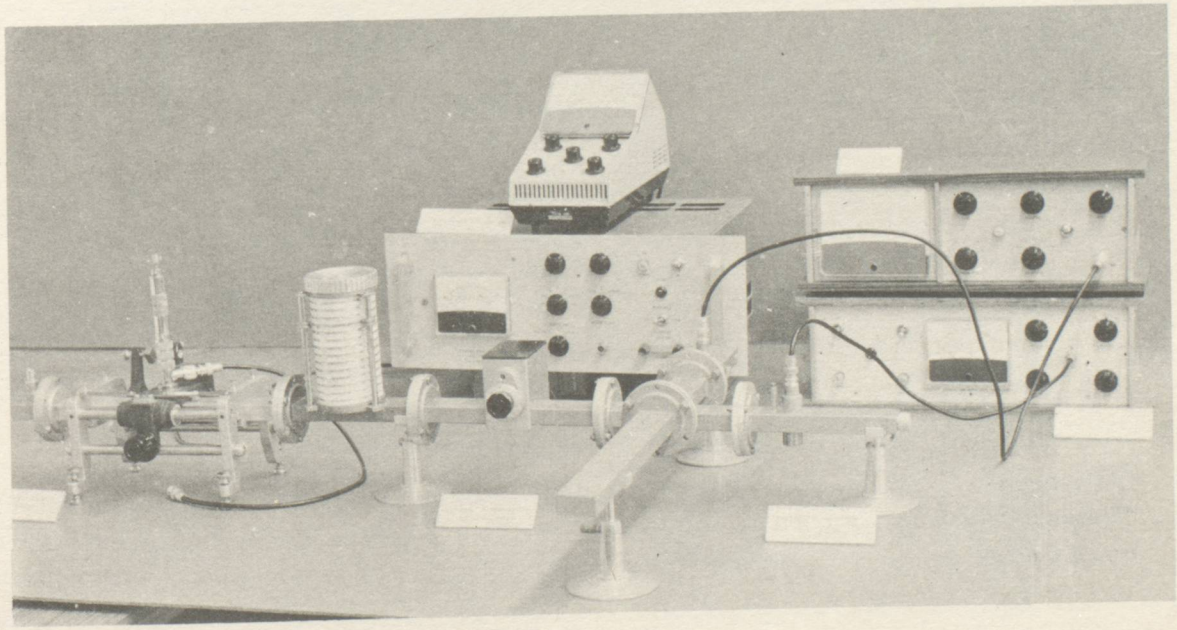
Microwave Engineering

As a result of various experimental programmes in the Institute an expertise in the ultra high frequency and microwave electronics area began to grow in the Institute. The work on nuclear instrumentation and particle accelerators gave the technology of microwave measurements, and fabrication of high power microwave devices, components and circuits. The work on Radio Astronomy led to expertise in antenna design, phased arrays, high sensitivity receivers and precision measurements. Magnetic resonance and microwave spectroscopy investigations in the Institute also contributed to the component and circuit development upto the millimeter wave regions. The Solid State Physics and Electronics Groups of the Institute gave opportunities for development and application of new solid state devices and materials. The large outlay in plans of the country for the microwave applications and the fast worldwide growth of technology in this area has opened up new challenges. The Institute began to contribute to this work since 1965 in a variety of areas.

One of the first applications was a programme of development of instruments and components like signal generators, power meters, frequency meters, impedance meters and standard components. The know-how developed was transferred in the late sixties to ECIL, which gave a start to its microwave instrument section. Another contribution was the development of antenna feeds and precision drawn waveguides in collaboration with BARC and ECIL to lead to subsequent regular production by those agencies.

Instruments and Components for Microwave measurement





Figs. 2A & 2B—Microwave Instrument and components developed and given to ECIL for production.

Microwave subsystems

The mircowave subsystems for radar were developed for the specific systems needed by the Indian Space Research Organisation. Various components and circuits for the transmitter such as pulse forming networks, high power switching circuits, high voltage pulse transformers, rotary joints, duplexers, high power isolators were developed. The receiver subsystems comprising of low noise front ends, A.F.C. local oscillators for multimode operation, and on line monitoring system for the radar were developed.

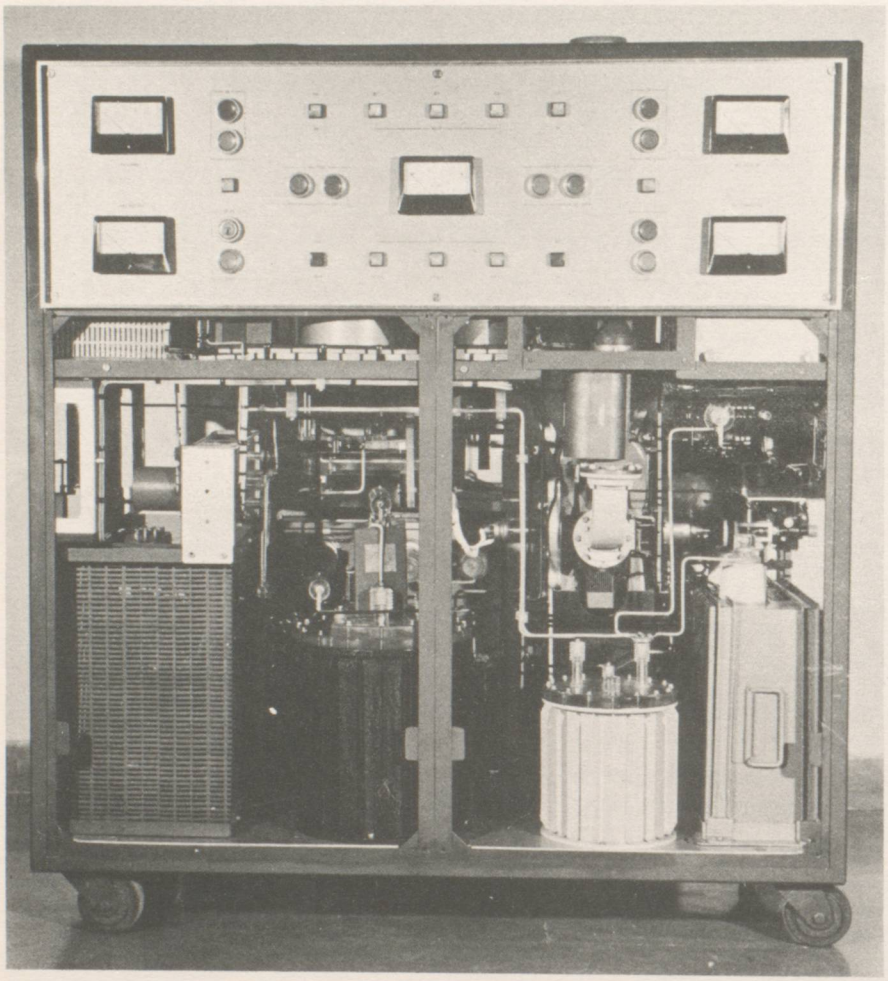


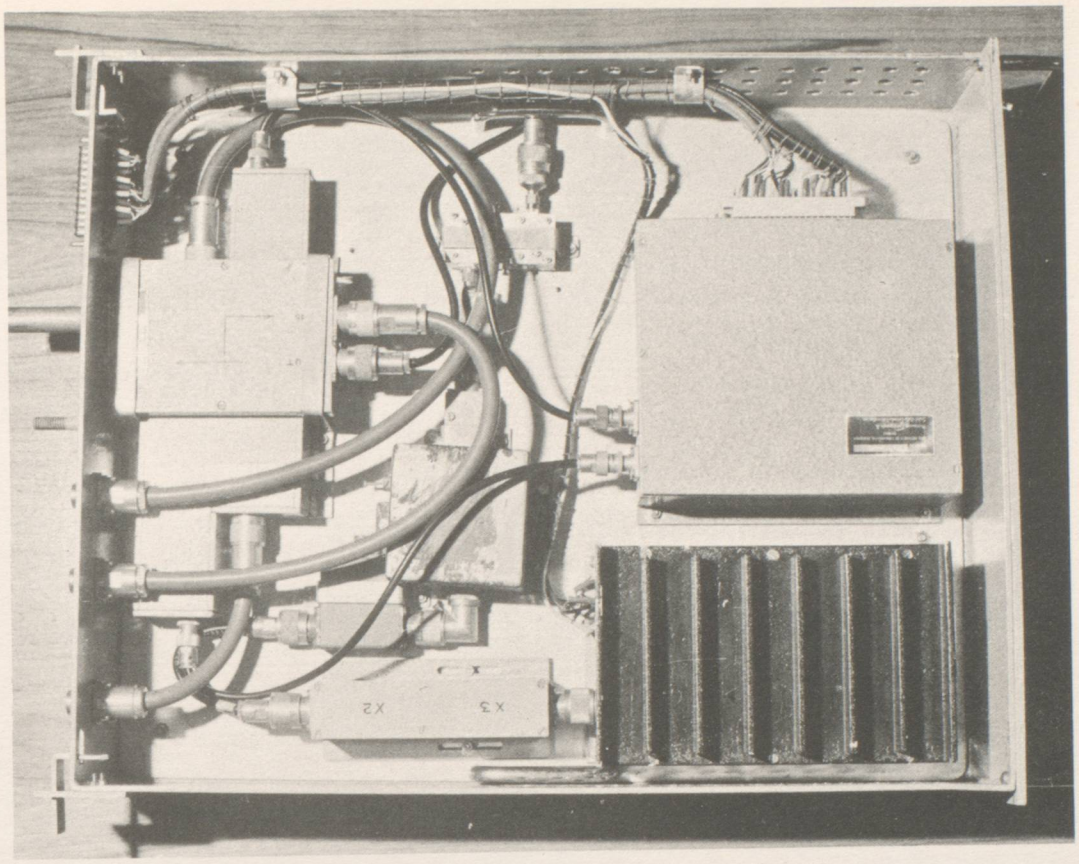
Fig. 3—Radar Transmitter subsystem for ISRO.

System Studies

Due to a number of problems referred to the Institute for consultation, system studies were also conducted frequently to assist in certain national programmes in the field of communications. Systems to which contribution were made were scatter and LOS communications, antenna feeds, D.F. equipments, navigation equipments, radar systems etc.

Microwave Components and Devices

The fabrication techniques for precision assemblies, vacuum devices were originally developed for the linear accelerator. They were applied to make a number of devices like gas switching TR tubes for radars, ferrite devices and waveguide components.



Figs. 4A & 4B — Multimode Radar Receiver Subsystem for ISRO.

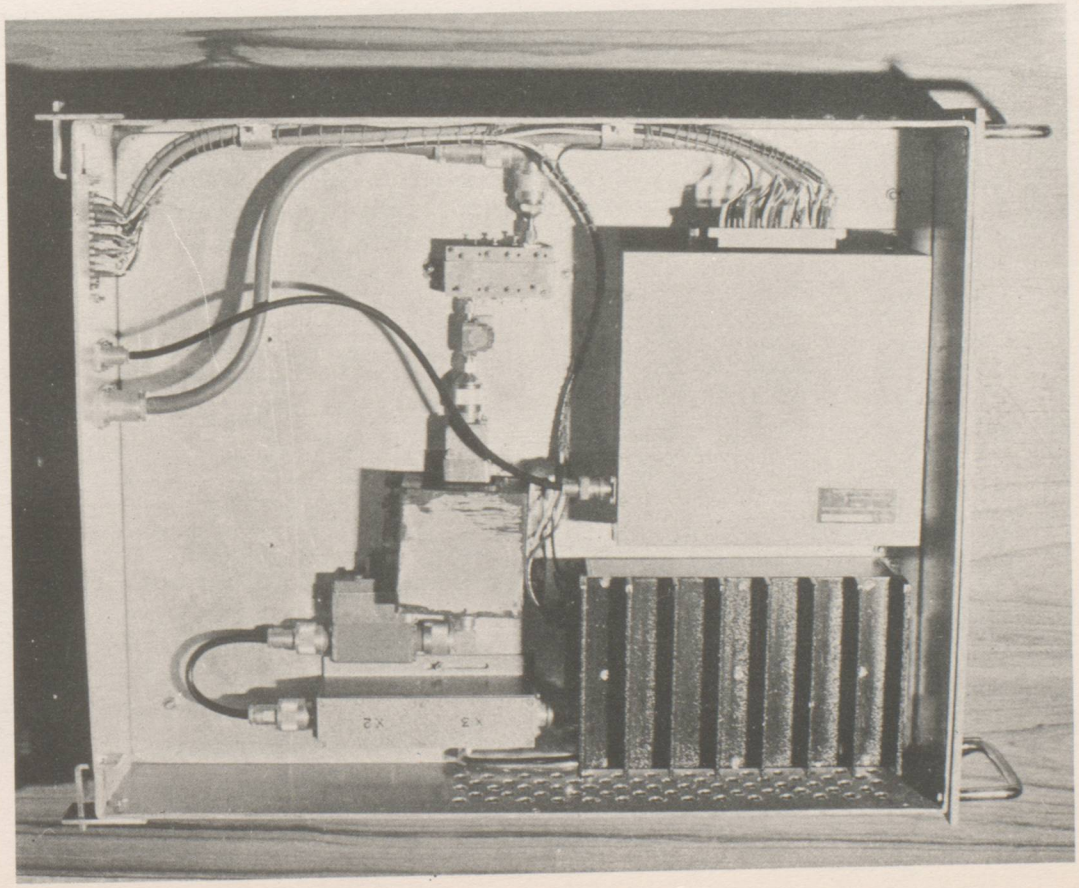




Fig. 5—Hydrogen Atmosphere Furnance for brazing microwave components and tubes.

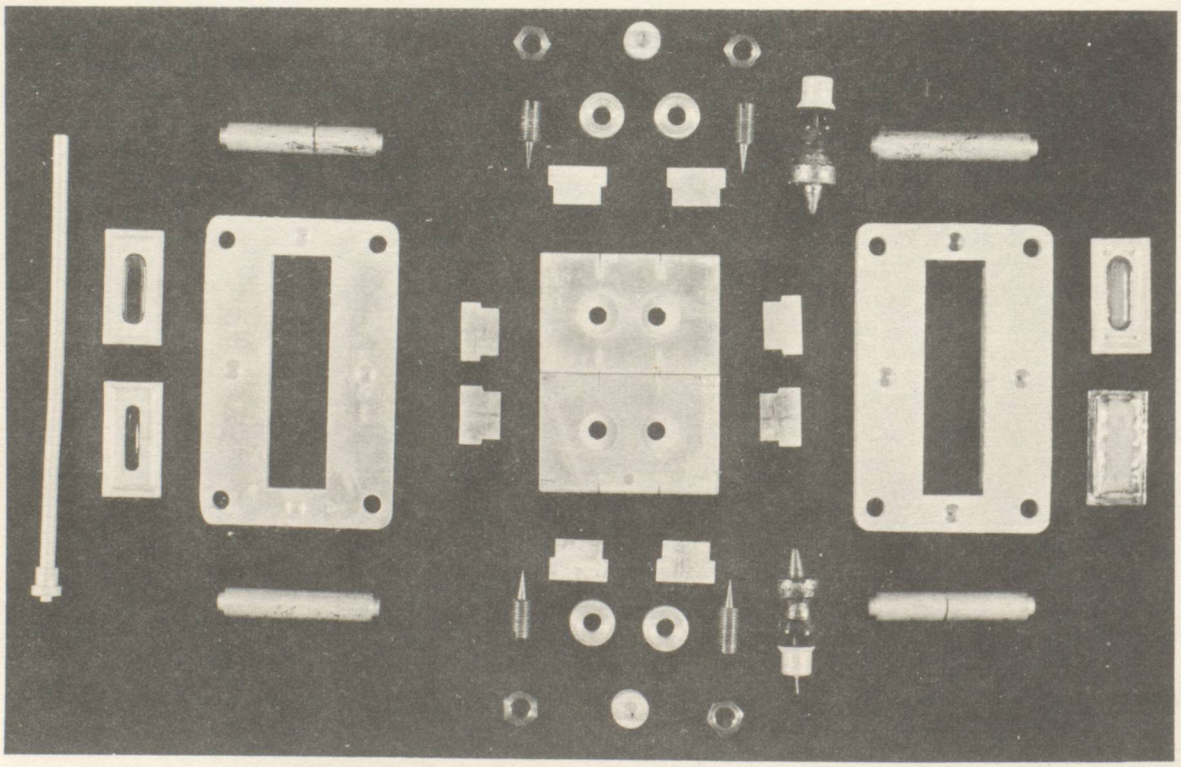


Fig. 6—Component parts of a typical TR tube.

Facilities were built up for technological processings like hydrogen brazing for vacuum devices, precision glass metal seals for microwave tubes, chemical processes for microwave components and tubes, vacuum systems, leak detection systems and mechanical engineering processes for batch production. In addition, facilities were built to make high and low power microwave measurements for a broad spectrum of frequencies. Specific items like TR tubes and waveguide components were made in batches to meet diverse equipment needs. Flexibility in the facilities built up made them adoptable to small volume production of a variety of sophisticated high cost microwave components and circuits needed in the microwave systems used in the country.

Microwave Solid State Devices and Circuits

In this activity circuits were developed for characterisation and applications of solid state devices like the Gunn, Avalanche and Schottky, PIN, and varactor diodes.

MICROWAVE ENGINEERING

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SOLID STATE ELECTRONICS

The first Indian made digital computer was designed and built in the Institute in the early sixties. This computer used thermionic valves and it was soon realised that the future generation of computers and computer based technology could be advanced only by resorting to the use of solid state devices. A decision was hence taken to set up within the institute a solid state electronics group which would devote itself to studies of physics and technology of semiconductor materials and devices.

The method of realising solid state devices depends on a number of intricately related processes and process equipments. Some of the processes are diffusion, photolithography, epitaxy, vacuum evaporation and sputtering. Further, all these processes have to be done in a very clean environment. Over the period of years, the group has been able to set up the basic facilities for semiconductor processing and has acquired considerable expertise in this area. Since in the field of semiconductors, physics and technology always go side by side, one supplementing the need of the other, the group has been engaged in both basic and applied research. Moreover, in view of the pressing demands in the country for many special types of semiconductor devices, some time-bound goal-oriented programmes sponsored by Government agencies have also been undertaken. Some of the highlights of the work are given below:

Digital Integrated Circuits

After establishing the planar technology in all its facets very early in the beginning, the group successfully developed TTL series monolithic silicon integrated circuits of the types 7400 and 7420 which are usually used in building the main frame of computers. This technology has been successfully transferred to Bharat Electronics Ltd, Bangalore where these devices are now produced in large numbers.

In continuation of the above work, various schemes of high speed computer circuits like low power Schottky TTLs and I^2L, which are latest in this type of technology, are in the process of being developed.

Discrete Devices

In the area of discrete devices, the group concentrated only on the problems of large area junctions primarily related to those of control rectifiers and thyristors. The group has been successful in fabricating quite a number of these devices with accepted specifications.

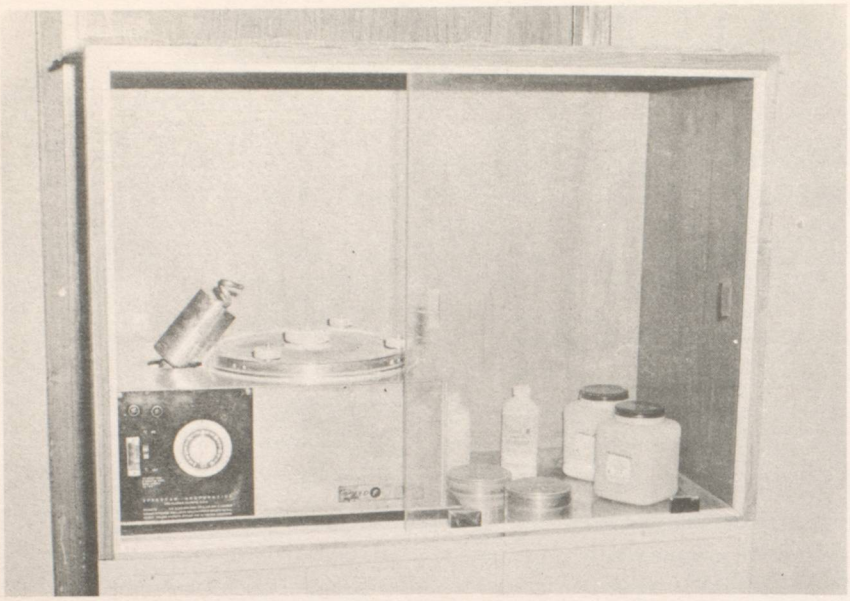


Fig. 1 — Mechanical polishing of Silicon slices.

Single Crystal Silicon — SiO_2 (Al_2O_3) — Polysilicon System:

So far as this system (though used in commercial circuits) has been studied only for certain types of growth. The growth process of polysilicon exert a lot of influence on surface states that is, the threshold voltage shifts. Nobody has attempted polysilicon deposition under RF discharge because of damage. The system being studied is for two different reasons — (1) to find the threshold shift due to damage and (2) polysilicon has been known to have a very high photovoltage. This fact can be used if the charge can be stored in semiconductor

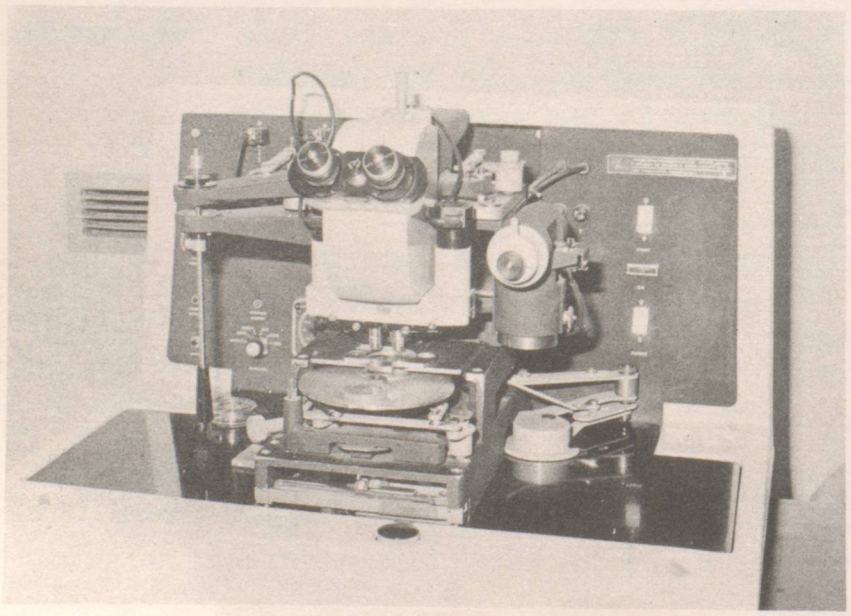


Fig. 2 — Photolithography.

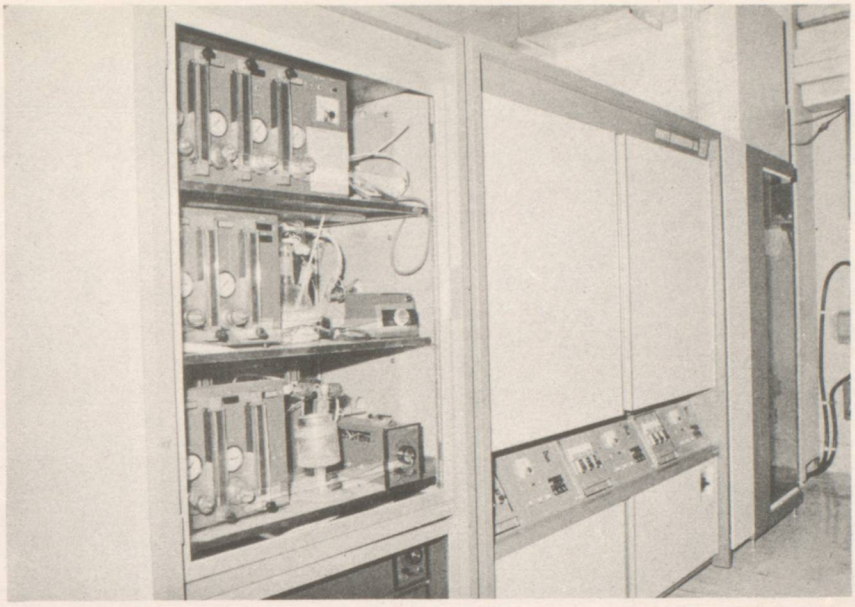


Fig. 3—Diffusion/Oxidation.

substrate due to solar radiation on polysilicon, and this charge can be dumped by a self-scan as they do in image sensing. This is a potential device area.

GaAs Programme

Studies on physics and technology of Gunn effect was initiated in 1969. Experimental studies were made on the formation of domains and their propagation in long GaAs samples. A correlation between impact ionisation within the domains and the carrier concentration in the material was established. Gunn diodes were fabricated using imported epitaxial wafers giving 5 mW in the X-band frequency range. In view of the importance of GaAs for various device applications, a programme has been initiated for growing GaAs by liquid phase epitaxy.

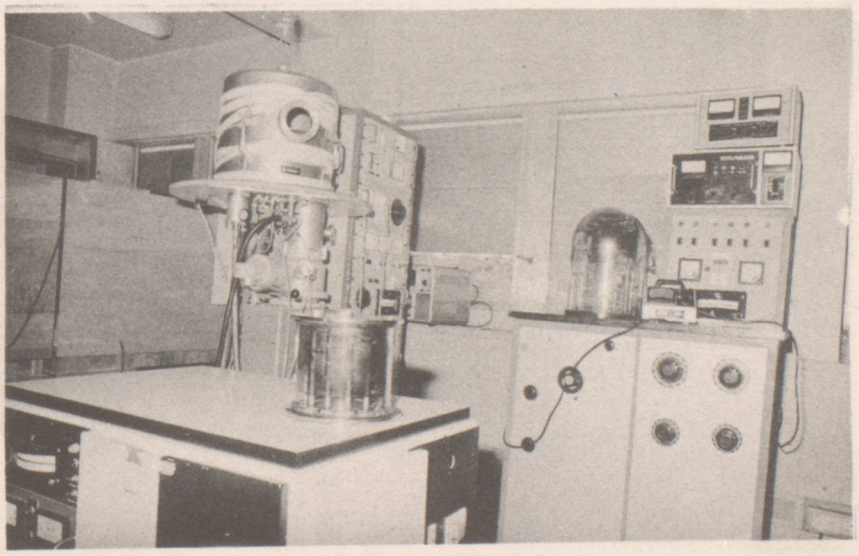


Fig. 4—Vacuum evaporation set-up.

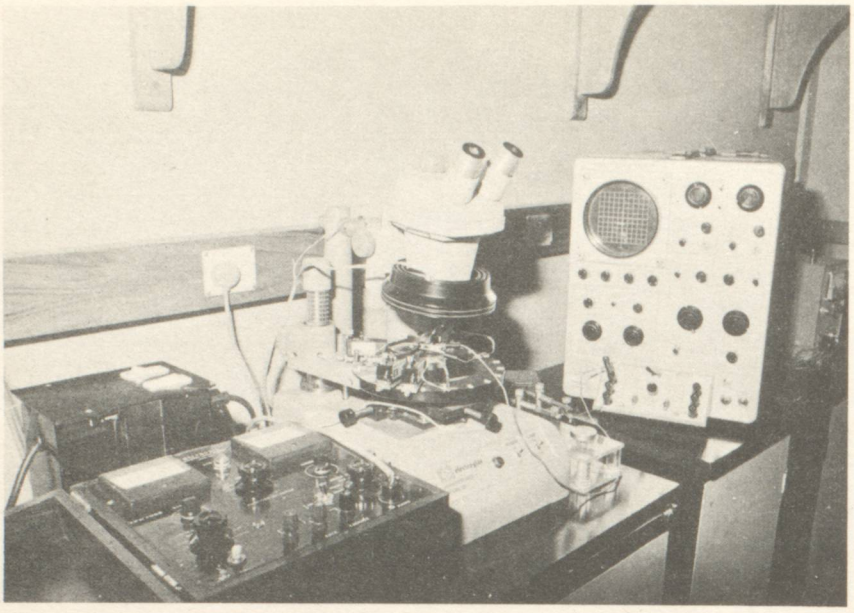


Fig. 5—Electrical evaluation of devices.

Thin film studies

The electrical properties of sputtered films of Nb_2O_5 have been investigated and a voltage controlled negative resistance is observed. Techniques are also developed for getter-bias sputtering of high purity metal films. Extensive work was carried out to investigate the properties of evaporated and sputtered films for applications in hybrid integrated circuits.

SOLID STATE ELECTRONICS

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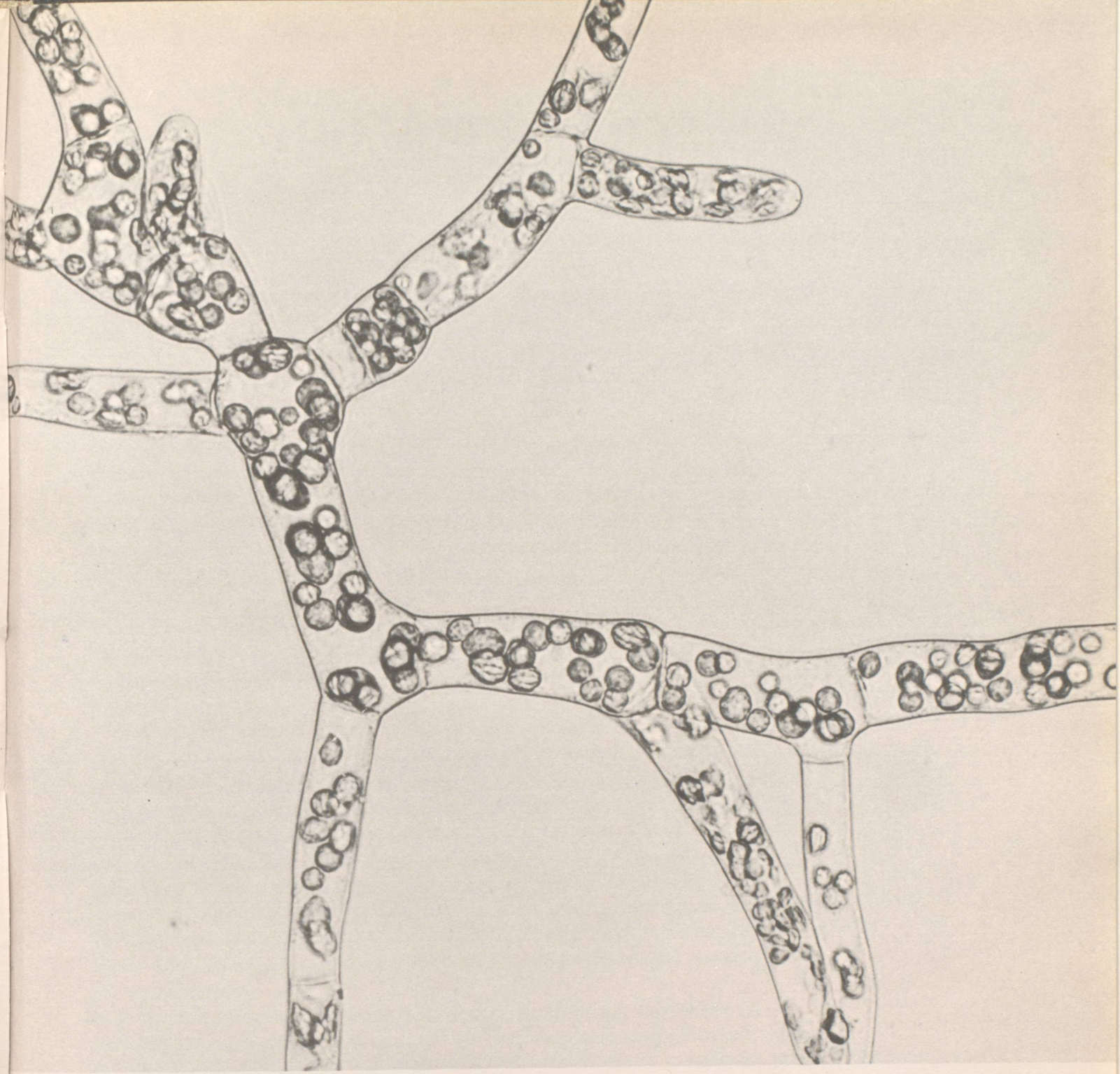
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MOLECULAR BIOLOGY

MOLECULAR BIOLOGY

During the past two decades, as a result of the application of ideas and techniques from physics and chemistry, life sciences have developed in a spectacular manner. Biological research has become increasingly quantitative and analytical. A major impetus in this direction came from the discovery that genes are made of DNA (or RNA), and from the structural work on proteins and nucleic acids that has led to an understanding of the function of these major macromolecules. It has become possible to comprehend fundamental biological processes, for the first time, in simple physico-chemical terms. The fertile field of research that has emerged from this approach has come to be called "molecular biology". It is an interdisciplinary field which on the one hand has its roots in physics and chemistry and on the other hand reaches into and merges with cellular and organismic biology. Scientists drawn from a variety of disciplines—theoretical physics, crystallography, organic and physical chemistry, genetics, biochemistry, biophysics, cellular physiology, microbiology and related areas have closely interacted and contributed to molecular biology.

Work in Molecular Biology at the Tata Institute of Fundamental Research was started in late 1962. One of the main reasons for starting work in molecular biology in an institution which had physics and mathematics as its main areas of activity, was the expectation that this would provide a unique opportunity for interaction between biology and physical sciences.

The growth of the research facilities for work in Molecular Biology was greatly helped by generous grants of £40,000 and £22,300 given to the Institute by the Wellcome Trust of London. The Molecular Biology Group consists at present of about 30 staff members. The programme of research centres around the chemical and functional aspects of proteins and nucleic acids, involving an intimate combination of biological, physical and chemical approaches. The basic equipment and the methodological skills that have been built up in this process will be indispensable for any future programme of research in modern biology.

Photomicrograph of Moss Protonema (Magnified 400-fold)



Fig. 1—General view of the Molecular Biology Laboratory.

Genetic exchange in bacteria—transfer, replication and recombination of DNA

Genetic transfer and recombination are universal biological processes underlying the morphological, biochemical and behavioural diversity observed among living things. The dynamics of DNA replication are, however, poorly understood. Questions concerning the coupling between DNA replication and cell division, the topology of replicative DNA, the unwinding and separation of chains, and the structure of the growing point remain unanswered. Due to this lacuna in our knowledge, a physico-chemical understanding of genetic transfer and recombination has not yet been achieved. We have therefore undertaken a study of the mechanism of the transfer, replication and integration of DNA in bacterial systems.

The kinetics of intragenic recombination in Escherichia coli *and its relationship with DNA replication*

As a rule recombination is measured by the frequency of genetic recombinants. We have, instead, measured recombination within a structural gene by following the rate of synthesis of its protein product. By the use of parents carrying nonsense mutations in the structural gene of alkaline phosphatase, it has been possible for us to analyse the time-course of crossing-over with a high degree of sensitivity.

Making use of a temperature-sensitive mutant of **E. coli** whose DNA replication can be switched off by elevating the temperature, it has been shown that DNA replication and recombination can be completely dissociated. This experiment rules out an entire class of hypotheses which invokes a coupling between these two processes.

Genetic transfer and DNA replication

During bacterial conjugation there is an oriented transfer of DNA from the donor to the recipient cell. We have found that this process is associated in the donor with switching on of DNA replication from a new origin and suppression of the normal vegetative replication. We are investigating the nature of the signals responsible for these events.

The structure of recombinant DNA

It has been shown previously that the recombinant DNA contains segments from both the parents. We have carried out experiments to measure the relative frequency of single- and double-strand insertions into the recipient chromosome after mating. The results indicate that an appreciable proportion or recombinant DNA receives only one strand from the donor, the other strand coming from the recipient. A study of the size distribution of donor strands that are inserted into the recipient chromosome has been made.

Transformation of **Bacillus subtilis**

A culture of **B. subtilis,** capable of undergoing transformation, is a mixed population consisting of a small proportion of cells that can take up DNA from outside and a majority of cells that do not. We have demonstrated that the former cells can be distinguished from the latter by virtue of their diminished buoyant density and smaller size. This finding has enabled us to separate the two types of cells from each other on equilibrium gradients.

An extensive progeny analysis of single transformed bacilli reveals that transformation, as a rule, appears to affect only one of the two strands of DNA. There is, however, a small proportion of clones which contains more than one type of recombinant. Such clones could arise either by a coincidence of independent single-strand insertion or from some unknown mechanism involving more than one strand.

Synthesis of RNA and protein

Much of molecular biology during the past decade has been concerned with the elucidation of the mechanisms involved in the synthesis of proteins encoded by the genes via template RNA molecules, called messenger RNA. Although a great deal is now known, our understanding of the dynamics of RNA and protein synthesis remains incomplete.

Current problems of interest in this field, towards which a substantial part of our work is directed, relate to the manner of regulation of protein synthesis in bacteria as well as in cells of higher organisms.

Polyribosomes and rapidly labelled RNA in bacteria

It is now known that ribosomal aggregates called polyribosomes form a major site of protein synthesis in the cell. We have sought to formulate a model of protein synthesis that attempts to explain the factors determining the observed size distribution of these structures.

The assumptions on which the model is based are as follows: The degradation of messenger RNA is in the same direction as that of its translation; the 5'- end of the messenger RNA when occupied by a ribosome is protected against degradation by an exonuclease; when free, it is either subject to degradation, or protection by a fresh ribosome, determined by the probability that the ribosome is either in one or the other of the two conformational states one of which possesses the exonuclease activity. One of the consequences of this treatment is that the sedimentation profiles of polyribosomes do not necessarily reflect the size distribution of the average messenger RNA of the cell but are a function, among others, of the half-life of messenger RNA. The model has been applied to a variety of other problems related to the tape theory of protein synthesis. It has provided a unified basis for a number of observations such as the kinetics of the labelling pattern of rapidly labelled RNA, distribution of nascent peptides on polyribosomes etc.

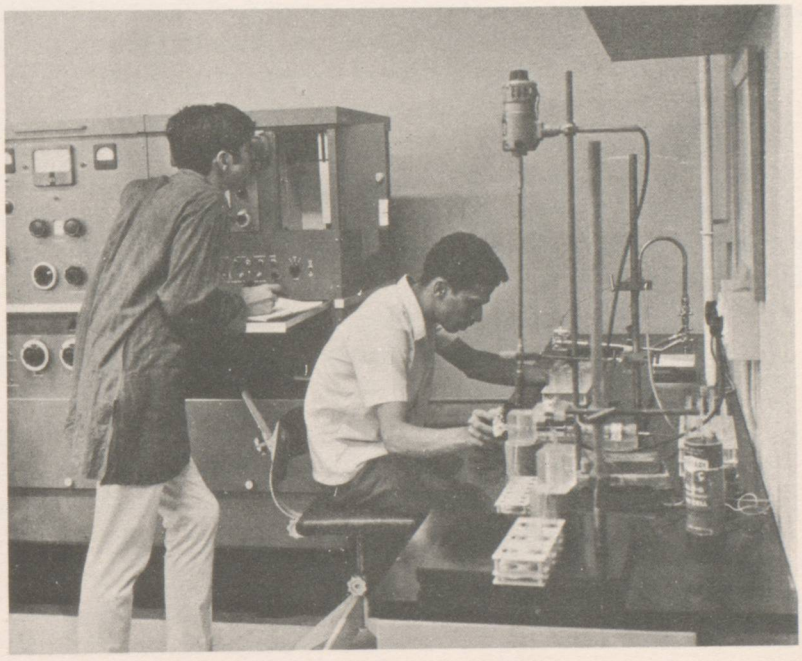


Fig. 2—Physical characterisation of macromolecules in the ultracentrifuge, in studies relating to the size and shape of biomolecules.

Biogenesis of ribosome

Kinetic analysis of earlier data in the literature on the synthesis of ribosomal RNA in higher cells indicated that methylation of RNA is not randomly distributed over the entire length of 32 S RNA, but is restricted to the segment corresponding to 28 S RNA. The unmethylated segment appears to be preferentially degraded during the maturation process.

In **E. coli** we have attempted to estimate the pool of free ribosomal proteins by immunochemical techniques, using specific antisera against four classes of these proteins. These experiments, which are in progress, indicate that ribosomal proteins constitute a major fraction of the free protein pool in these bacteria.

***Regulation of aryl sulphatase of* Aspergillus nidulans**

Our present knowledge of the genetic regulation of enzyme synthesis stems mainly from experiments on bacteria. An approach to the problem of control mechanisms in higher organisms has been provided by our observation that the synthesis of aryl sulphatase in the eukaryotic fungus **A. nidulans** can be controlled over wide ranges. The enzyme is subject to repression by inorganic sulphate, cysteine and methionine. When derepressed, the culture possesses aryl sulphatase activity in two distinct protein fractions. These have been characterised in partially purified forms.

Our investigation of the mode of regulation of this enzyme shows some novel features in its synthesis. The formation of active sulphatase on derepression involves two distinct steps. One of these requires continued protein synthesis, while the second step converts the enzymically inactive protein into active enzyme. Since the addition of a repressive metabolite arrests sulphatase formation almost instantaneously, we are led to conclude that both the steps in the formation of the active enzyme are regulated by feedback.

Preliminary genetic evidence indicates that mutant strains of this fungus insensitive to one or more of the repressive metabolites belong to at least six different cistrons regulating aryl sulphatase.

***Synthesis of alkaline phosphatase in* E. coli**

We have found that when the structural gene for phosphatase is introduced into a constitutive recipient lacking one of the regulator genes R2, there is a small pulse of phosphatase synthesis at the time of entry. Extensive translation of the phosphatase gene, however, takes place after a considerable lag period. Mutations in the other regulator gene R1 considerably diminish this lag. The R1 gene thus appears to be involved in regulating the synthesis of an inducer-like compound which is necessary for full expression of the phosphatase gene. The initial pulse of phosphatase synthesis is apparently due to some form of escape synthesis in the donor, associated with changes in the donor chromosome during gene transfer.

***Genetic control of glycolytic enzyme synthesis in yeast and* E. coli**

Our interest in the genetic regulation of glycolysis stems from a number of special biochemical features of this pathway, viz. its functional reversibility, its multiple entry and exit points, and the constitutive nature of its enzymes.

A study of the regulation of the synthesis of glycolytic enzymes has been conducted in yeast. Our results indicate that induction by sugars involves increased synthesis of the same proteins which are present in the uninduced culture. Induction involves new protein synthesis; we do not know yet if new messenger RNA synthesis is also necessary. In a strict sense the glycolytic enzymes do not behave as a co-ordinate group, although in the steady state they display co-ordination. Experiments using mutants blocked in the early



Fig. 3—Investigations on the dynamics of cellular reactions: Microestimation of enzymes and substrates by fluorescence analysis.

glycolytic reactions indicate that glucose 6-phosphate is the primary inducing signal for all the seven enzymes involved in the catalytic conversion of fructose 1, 6-diphosphate to pyruvate. Hexokinase and fructose 6-phosphate kinase are induced presumably by mannose 6-phosphate. Phosphoglucomutase, pyruvate decarboxylase and alcohol dehydrogenase fall outside either of these categories. One other feature of the synthesis of most of the glycolytic enzymes is that their level in uninduced culture appears to be set by an internally generated pool of the inducer, suggesting that constitutive synthesis requires an internal inducing signal.

Investigations on the genetic organization underlying glycolytic enzymes have been recently initiated in our laboratory. We have found that single mutational events generate multiple defects leading to the loss of some of these enzymes and a number of other functions. Characterization of some of these mutants has allowed us to identify a gene that controls the synthesis of β-galactosidase as also its structure. This gene in certain mutated states also affects the synthesis and structure of the following enzymes: glucose 6-phosphate dehydrogenase, 6-phosphogluconate dehydrogenase, fructose 6-phosphate kinase, triose phosphate isomerase, glyceraldehyde 3-phosphate dehydrogenase and phosphoglycerate mutase. There are indications that this gene determines a ribosomal function.

During the course of this work we have found a glucokinase in yeast. We have characterised the enzyme and proposed a mechanism for the catalytic reaction.

Enzyme structure and function

One of the important problems in contemporary biology concerns the relation between the structure of enzymes and their function, and the consequences of this relationship for metabolic control. Elucidation of the chemical and three-dimensional structure of a number of proteins has brought to light the molecular mechanism of catalysis and the associated phenomenon of control of reaction velocity. Most enzyme reaction mechanisms, however, remain obscure. We have undertaken a study of the catalytic and control mechanisms of a number of enzymes and enzyme systems.

Alkaline phosphatase of* E. coli—*active site and reaction mechanism

The current hypothesis regarding the catalytic function of this zinc-containing metallo enzyme is that a phosphorylated enzyme with a serine phosphate residue is an intermediate in the hydrolysis of phosphate esters. Nothing is so far known regarding its primary sequence, the nature of other residues constituting the active site, and the role of the metal in catalysis.

A kinetic analysis based upon the variation of the kinetic parameters of the enzyme as a function of pH, temperature and the dielectric properties of the solvent has been completed. The results indicate that a water molecule coordinated to the zinc atom functions in enzyme-substrate binding and the imidazolium group of a histidine residue participates in catalysis. Our present attempts are directed towards mapping the residues at the active site by selective chemical modification.

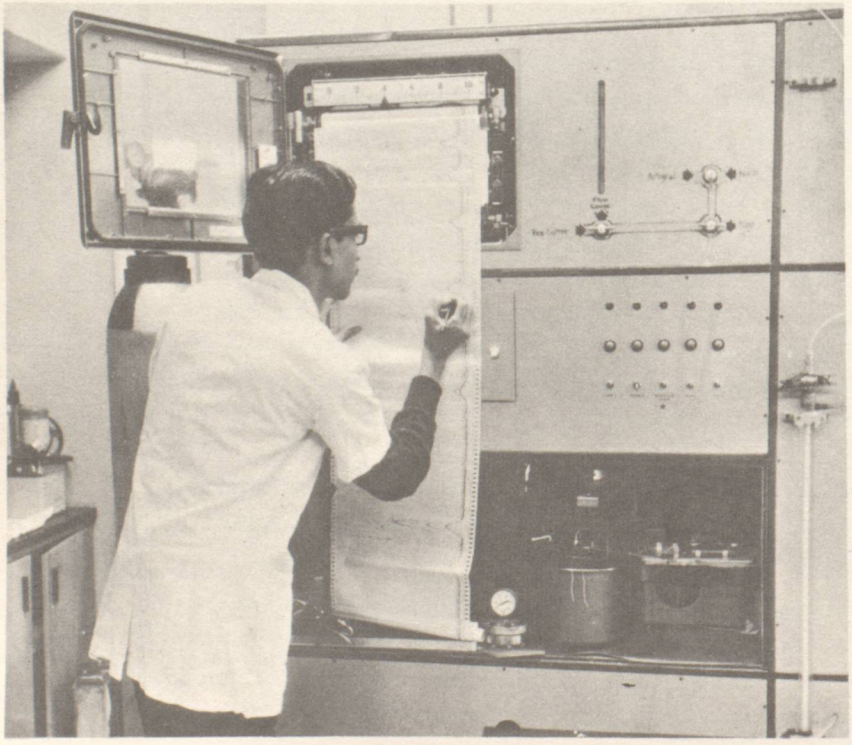


Fig. 4—Studies relating to the chemical structure of proteins: chemical composition of proteins using the amino acid analyzer.

Brain hexokinase

The inhibition of hexokinase by glucose 6-phosphate seems to be the major determinant in the control of glycolysis in the mammalian brain. However, because of the nonavailability of the pure enzyme, not much else is known about its other regulatory features or about its interaction with other possible regulatory metabolites. We have purified the enzyme from beef brain cortex to a nearly homogeneous state. We are now trying to crystallize the enzyme.

Regulation of ATP synthesis following conduction in frog sciatic nerve

We have sought an answer to the question whether regenerative metabolism for ATP synthesis is called into play during conduction of nerve impulses. Our work with the frog sciatic nerve indicates that a nerve bundle at rest is an energetically 'charged' system. Conduction depletes energy reserves and causes an activation of metabolism at the fructose 6-phosphate kinase step. Rapid glycolytic resynthesis of ATP ensues and the system returns to its initial state.

Control of glucose utilization in yeast

The fact that sugar utilization is controlled in cells has been known since the days of Pasteur. An explanation of how yeast cells achieve this has so far been elusive. This applies to our attempts as well. However, a number of interesting facts have emerged. One is that the entry of glucose into the yeast cell and its subsequent utilization are oscillatory processes. This has suggested that some metabolite formed as a result of glucose addition acts reversibly on both these reactions. Although we have not been able to identify the control chemical, it does not appear to be glucose 6-phosphate alone. This seems to be indicated by experiments using mutants of yeast which lack one or more of the early glycolytic enzymes.

Future programme

We have so far described the work carried out in this laboratory in the field of macromolecular structure and function in microorganisms. In the majority of the cases, the conclusions reported here have generated several intriguing possibilities which, if pursued, should certainly strengthen our understanding of the molecular basis of living processes. These problems, will therefore, continue to be important areas of activity in our laboratory. In planning for the future, however, we fully recognise the changing frontiers of biological enquiry. As a result, we have initiated work on the problems of development and differentiation in higher organisms.

It is generally accepted that during embryonic growth in higher organisms, the newly produced cells differentiate into different structural and functional groups as a result of selective and programmed expression of genes. The theories of gene regulation that have emerged from the study of microbial systems provide useful clues to the manner in which this regulation is brought about. However, the cells of higher organisms display certain genetic, cytological and biochemical features that are peculiar to them. We are presently exploring

systems in which the relevance of these features to the programming of genes can be suitably investigated. With this in mind, we have set up facilities for culturing plant and animal cells since these techniques will inevitably play a crucial role when these problems begin to receive greater emphasis in our laboratory.

In the field of development, we are actively interested in unfolding the relationship between RNA and protein synthesis on the one hand and early embryonal development on the other. We have already investigated this problem during embryonal development of sea urchin where we have shown that the distinct shift in RNA metabolism after gastrulation is associated with a significant increase in the transport of RNA from the nucleus to the cytoplasm. The biological significance of this observation continues to be an interesting unsolved question. Another attractive system for studying chemical events during early development is that of germinating seeds in which the newly synthesized proteins utilise previously stored messenger RNA. Experiments are being designed to explore the biochemical nature of the stored messenger RNA whose existence has also been demonstrated in several other developing plant and animal systems.

Our present efforts in the area of differentiation are concentrated on understanding the mechanism by which plant and animal hormones regulate the expression of specific genes in different cell types of an organism. A possible approach to this problem would be through the isolation of mutants, whose response to the hormone is altered. We have therefore chosen two systems which lend themselves easily to genetic and biochemical techniques that have been fruitfully exploited in microorganisms. One of these is a moss in which kinetin, a plant hormone, regulates bud differentiation in the protonema. Besides exhibiting a well-defined response to cytokinins, this organism is haploid and can be cloned. The other system is that of cultured animal cell lines (HeLa and hepatoma) in which hydrocortisone, a steroidal hormone, induces the synthesis of specific enzymes. We are currently devising methods to isolate mutants which would be defective in their response to these hormones. In a related line of work, we have developed a method for purification of hormone-specific receptor from the cytoplasm of rat liver in which hydrocortisone induces the synthesis of several gluconeogenic enzymes. Efforts are underway to evolve a cell-free system in which one can analyse the role of this partially purified receptor in the hormone-induced response.

Besides the problem of development and differentiation, neurobiology is an exciting, though as yet a relatively uncharted field of modern biology. The growth of the neutral network and its function in the processing, storage and retrieval of information present challenging problems which are not so readily comprehensible within the frame-work of contemporary molecular biology. In collaboration with members of the Computer Group, who have been actively engaged for some time in the problems of visual perception, we have taken the initial steps to set up a programme in neurobiology.

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BASIC DENTAL RESEARCH

Programme of Basic Dental Research

On June 15, 1961 a Dental Surgeon was appointed to give full dental care and treatment to the staff of the Institute. This was the beginning of the Dental Section.

From 1961 to 1964 the Section was engaged primarily in the task for which it was set up i. e. in giving dental treatment to the staff of the Institute. Early in 1964, a proposal was put to the Director Dr. H. J. Bhabha, to start a Dental Research Unit, to undertake basic research in this field. With the facilities already available in the Dental Section and the research atmosphere of the Institute it was felt that this would be both appropriate and relatively easy.

Among the first few projects undertaken by the Unit, the most important was a follow-up examination of Bombay policemen. In 1959 about 4,700 Bombay policemen had been examined for finding out the prevalence rates of oral leukoplakia (which is a precancerous lesion), and its possible association with tobacco chewing and smoking habits. The findings were reported in the Indian Journal of Medical Research, (*49*, 393-398, 1961). In 1964, five years after the first examination the same policemen who were examined in 1959 were re-examined to find out whether there were any changes in mouth conditions. No transformation to oral cancer was found and the findings were reported in the Journal of Oral Surgery, Oral Medicine and Oral Pathology, (*28*, 372-388, 1969). At present a second follow-up of the same Bombay policemen is going on and it is almost complete.

At the initial stages of this research activity, Prof. J. J. Pindborg of the Royal Dental College, Copenhagen, was in India and it was decided to apply for a grant from the National Institutes of Health, U. S. A. for a large scale epidemiological study of oral cancer. Oral cancer was selected because of the high prevalence of this disease in India. It has been reported that 40 to 60% of all cancers prevalent in India are oral cancers; if so, one of the most important cancer control measures would be prevention of cancer of the mouth on a country-wide basis.

The Oral Cancer Project

In 1966 this project got a big impetus through a 3 year grant from the National Institutes of Health, U. S. A. to conduct a survey of oral cancer and

precancerous conditions in the rural Indian population; PL 480 funds were allotted for this. Consequently an Oral Cancer Research Project was started with Dr. Fali S. Mehta as the Principal Investigator and Prof. J. J. Pindborg of the Royal Dental College, Copenhagen, Denmark as the Co-Principal Investigator.

Dentists were recruited and were trained for diagnosing oral cancer and oral precancerous conditions. Pilot surveys were conducted in the villages of Ambegaon Taluka of Poona District in Maharashtra mainly to provide training for the project staff in actual field work and to standardize methods of clinical diagnosis.

Survey

The full scale epidemiological survey was conducted in five districts of four states in India. The selected districts were Bhavnagar district in Gujarat, Ernakulam district in Kerala, Srikakulam in Andhra Pradesh and Singhbhum and Darbhanga in Bihar. In each of these districts villages were selected on the basis of random sampling. In selected villages all individuals above the age of 15 years were examined on a house-to-house basis. Over 10,000 individuals were examined in each district. All important lesions were photographed in colour by using Polaroid Land R Cameras so that an instant picture could be obtained for documentation.

LESIONS	GUJARAT	KERALA	ANDHRA PRADESH	BIHAR	
	BHAVNAGAR	ERNAKULAM	SRIKAKULAM	SINGHBHUM	DARBHANGA
ORAL CANCER	0.03	0.12	0.10	—	0.01
LEUKOPLAKIA	1.7	1.7	4.9	0.2	0.2
PRELEUKOPLAKIA	4.1	2.4	2.9	0.5	0.7
SUBMUCOUS FIBROSIS	0.2	0.4	0.04	—	0.07
LEUKOKERATOSIS NICOTINA PALATI	0.2	0.3	9.5	0.04	—
LEUKOEDEMA	0.1	0.3	0.2	0.02	0.02
LOCALIZED ATROPHY OF TONGUE PAPILLAE	0.1	1.0	0.1	0.1	0.04
NUMBER OF INDIVIDUALS EXAMINED	10071	10287	10169	10048	10340

Fig. 1—Prevalence of oral lesions in five districts of India, obtained from a house-to-house survey in villages selected by random sampling; a total of 50,915 villagers were involved in this survey, one of the most exhaustive ones every made for oral cancer.

Cytologic smears and biopsies were also obtained of the lesions in question. In all, 50,915 individuals were examined and 1,115 biopsies were obtained. The project is greatly indebted to the Polaroid Corporation for the supply of cameras and films without which documentation of the type carried out would not have been possible.

Results

The main findings from the survey can be listed as follows:

1. The finding and reporting of a peculiar smoking habit, of clay pipe smoking, unreported so far, in the Bhavnagar district of Gujarat state. This habit was associated with large number of precancerous lesions (leukoplakia and preleukoplakia) which were mainly confined to the labial mucosa.

2. The habit of reverse smoking of chutta (hand made cigars) i. e. smoking with the burning end inside the mouth, is widespread in the Srikakulam district of Andhra Pradesh. This habit is much more common amongst females than in males. It was found to be associated with a large number of precancerous lesions mainly to the palate.

3. The prevalence of oral cancer and precancerous conditions was found to be very high in Ernakulam district of Kerala and the incidence comparatively very low in Singhbhum and Darbhanga districts of Bihar. This confirms the earlier observations that prevalence of oral cancer is high in South India and low in North India.

These findings have been reported in the following publications:

1. British Journal of Cancer, (*22*, 646-654, 1968).
2. British Dental Journal, (*127*, 73-77, 1969).
3. Cancer, Journal of American Cancer Society, (*24*, 844-861, 1969).
4. Indian Journal of Cancer, (7, 18-23, 1970).
5. British Journal of Cancer, (*24*, 1970).

Follow-up Study

In 1969, when the period covered by the first grant was over, a new grant was obtained to conduct a follow-up study among the individuals examined during the first survey; the proposal was to follow-up all individuals whether normal or with lesions.

The objectives of the follow-up study are as follows:

1. For patients registered *with* lesions

   (a) incidence rate of malignant transformation of the various precancerous lesions;



Fig. 2—A man from Bhavnagar district in Gujarat State, smoking a "hookli" (clay pipe). About 15% of the adult males above 15 years are addicted to this habit.



Fig. 3—A lesion on the lip mucosa associated with hookli smoking. Similar changes were found among 26% of the hookli smokers.



Fig. 4—A woman from Srikakulam district, Andhra Pradesh, smoking "chutta" (cigar) in the reverse manner i. e. keeping the burning end inside the mouth. This habit is prevalent in about 50% of the adult population (above 15 years), mostly females.

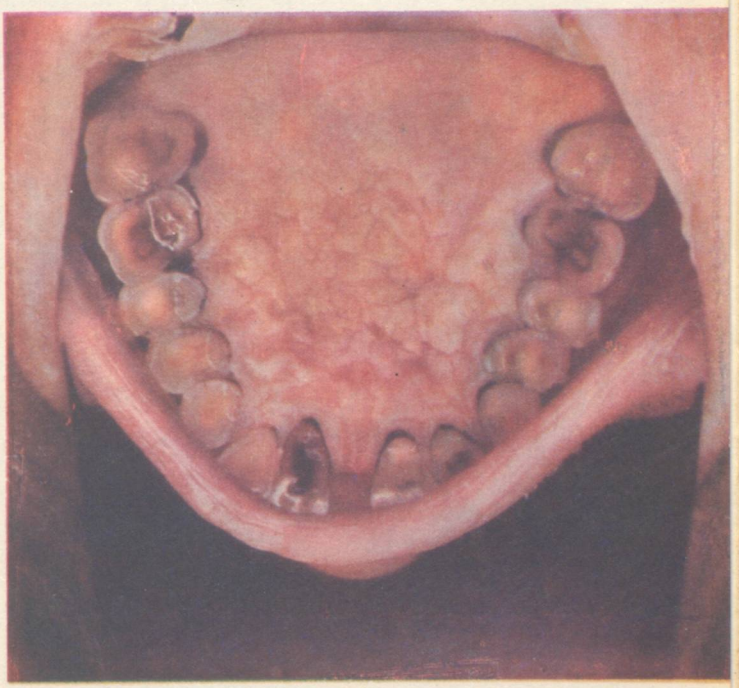


Fig. 5—A lesion on the palate associated with reverse smoking. Similar changes were seen among 25% of the reverse smokers.

(b) incidence rate of oral cancer at sites other than the lesion;
(c) a possible reversibility of epithelial atypia;
(d) rate and degree of spontaneous regression of a lesion;
(e) a possible transition of preleukoplakia into leukoplakia; and
(f) the influence of habit change upon a lesion

2. For individuals registered *without* lesions

(a) the incidence rate of oral precancerous conditions; and
(b) the incidence rate of oral cancer without evidence of oral precancerous conditions.

By May 1970 the first follow-up was completed; since then a second follow-up has been in progress. In the first follow-up 38, 168 individuals were re-examined. The percentage in originally examined cases that could be re-examined in the follow-up varied from 68% to 84% in the different districts.

Other Programmes

The Dental Research Unit has also taken up a project in the rural areas of Poona district to find out the prevalence rates of oral cancer and oral precancerous conditions and their possible associations with tobacco chewing and smoking habits. The target is to examine 100,000 individuals. The whole of the Ambegaon Taluka and parts of the Junnar Taluka have been surveyed and about 75,000 individuals have been examined.

In 1966, WHO established International Reference Centres (IRC) for oral precancerous conditions with headquarters at the Royal Dental College, Copenhagen, Denmark. The Basic Dental Research Unit of TIFR was selected as one of the collaborating centres. The Unit is working very actively as a collaborating centre and contributing a large amount of material to the IRC. In January 1970 a very successful meeting of investigators of oral precancerous conditions, of the International Reference Centres, was organized at the Institute.

The Unit is also actively engaged in a programme of seminars and symposia organized in India as well as abroad to publicize aspects related to oral cancer in India.

In addition, the Dental Research Unit is about to start an evaluation programme for evaluating silver amalgam, a common filling material used in India. This will help to test and standardize this material; no such facility exists at the moment for such evaluation.

BASIC DENTAL RESEARCH

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A Correlative Histocytological Study of Epithelial Atypia in Leukoplakia and Submucous Fibrosis Lesions amongst Indian Villagers in a Mass Screening Programme
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Occurrence of Epithelial Atypia in 51 Indian Villagers with Oral Submucous Fibrosis
Brit. J. Cancer, *24*, 253, 1970.

GENERAL FACILITIES IN THE SCHOOL OF PHYSICS

HOT LABORATORY

The Hot Laboratory is used for the storage of highly radioactive materials, for enforcing health physics procedures and for the preparation and purification of radioactive materials required for various experimental projects in the Institute. It is an essential facility for the research programmes of the Institute in the areas of nuclear physics, solid state physics, chemical physics and molecular biology. By confining the storage and chemistry of radioactive materials to the Hot Laboratory, it is feasible to reduce the chances of radioactive contamination in the main laboratory areas and to carry out work in fields such as Isotope Geophysics which involve extremely low levels of activity.

Methods have been developed in the Hot Laboratory for the preparation of carrier-free Niobium-92 and Copper-64 by solvent extraction from materials irradiated in a reactor, and of Terbium-161 from reactor irradiated Gadolinium by using ion exchange. The vacuum evaporation technique has been utilized for obtaining carrier-free Indium-113m from irradiated tin. The electro-deposition technique has been successfully exploited for preparing carrier-free isotopes of certain refractory elements.

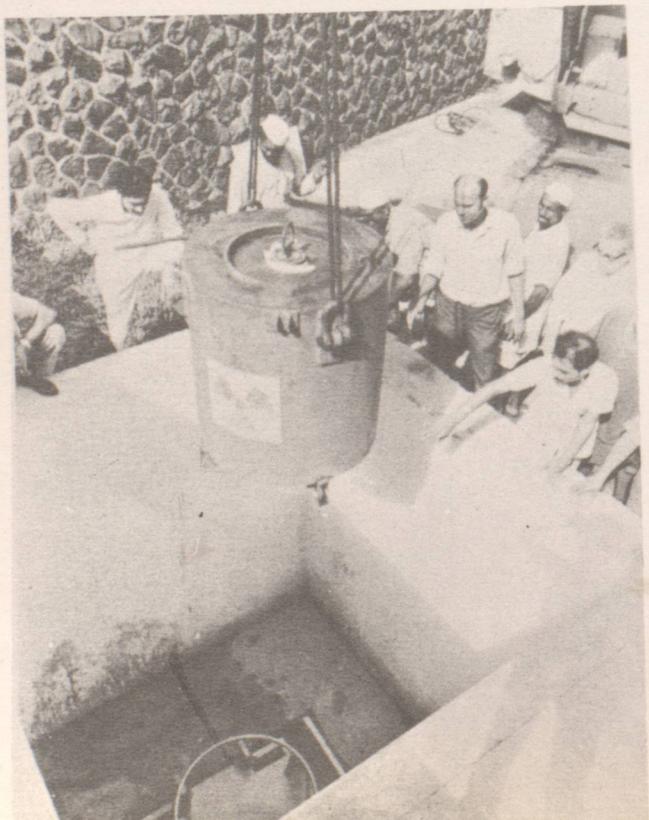


Fig. 1—A 3000 Curie Cabalt-60 Source in the process of installation in the basement of the Institute. This irradiation facility is being used for research programmes in solid state physics and radiation chemistry.

Rapid radio-chemical separation and milking experiments have been carried out: (a) to separate Strontium-90 from Yttrium-90; (b) to study the decay schemes of Platinum-201 and Platinum-197m; and, (c) to estimate the upper limit to the half life of Gold-199m isomer.

In addition to radiochemical work, the staff of the Hot Laborartory is also engaged in the study of organic reagents in inorganic analysis. Detailed spectrophotometric studies of certain metals with Resacetophenone oxime have been conducted in order to ascertain its use in analysis. The reagent has also been employed for solvent extraction of certain carrier-free radioactive nuclides and for the preparation of short-lived carrier-free Technetium-101.

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Standard Resacetophenone Oxime in Spectrophotometry
Curr. Sci., *27*, 439, 1958.

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BHATKI, K.S., K.P. GOPINATHAN and A.T. RANE
Preparation of High Specific Activity Terbium-161 from Gadolinium
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On the Preparation of Neutron Deficient Nb^{92} in High Specific Activity
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Proc. Ind. Acad. Sci., *LVIII*(3A),177, 1963.

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On the Solubility of Copper and Nickel Complexes of RAPOX in Organic Solvents
Proc. Ind. Acad. Sci., *LVIII* (4A), 202, 1963.

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J. Chem. Eng. Data, *9*, (2), 175, 1964.

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BHATKI, K.S., and A.T. RANE
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Ind. J. Chem., *3*, (3), 133, 1965.

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Radiochemical Separation and Purification of Ba^{140} and Rapid Milking of
Ind. J. Chem., *4*, (6), 261, 1966.

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Electrodeposition of Carrier-Free Zr^{92} from an Aqueous Bath
J. Radioanal. Chem., *1*, 331, 1968.

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Preparation of Carrier-Free Copper-64, 67 Nuclides by Liquid-Liquid Extraction
J. Radioanal. Chem., *2*, 73, 1969.

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Proc. Nucl. and Radiation Chem. Symp., Pune, 211, 1967.

EPHRAIM, D.C., and K.S. BHATKI
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Proc. Nucl. and Radiation Chem. Symp., Pune, 386, 1967.

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Preparation of Carrier-Free Ac
Radiochim. Acta, *3*, 123, 1964.

1969

MATH, K.S., K.S. BHATKI and H. FREISER
A Highly Sensitive Extraction-Photometric Method for Nickel with Dithizone and Phenanthroline
Talanta, *16*, 412, 1969.

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Radiochemical Studies: The Production of Certain Carrier-Free Nuclides
Bombay University, 1966, M.Sc.

1968

EPHRAIM, D.C.
Studies in Low Concentration Chemistry with Special Reference to the Isolation of Certain Carrier-Free Nuclides
Bombay University, 1968, M.Sc.

1969

PALKAR, V.R.
Isolation of Certain Radioactive Nuclides by Vacuum Evaporation
Bombay University, 1969, M.Sc.

JOSHI, B.M.
Studies in the Electrodeposition of Certain Radioactive Nuclides
Bombay University, 1969, M.Sc.

CRYOGENIC FACILITIES

For a variety of experiments being carried out at the Institute over the past decade by several of the research groups, it has been essential to make observations through the use of liquid helium and nitrogen. In view of this, a Collins Helium Liquefier from Arthur D. Little Co., U.S.A. with a liquefying rate of 6 litres/hour along with a low pressure repurifier unit was installed in 1962 in a building specifically built for the purpose. Laboratories requiring low temperature facilities on a regular basis were connected to the helium plant by copper tubings for the helium gas.

In the beginning, the supply of liquid helium was irregular for two main reasons: one was the irregular supply of liquid nitrogen by the local suppliers and the other was the slow repurification rate of the recovered helium gas. Both these bottlenecks were eliminated a few years ago, by installing in May 1967 a 4-cyliner Philips liquid nitrogen plant with a liquefaction rate of about 25 litres/hour and in 1968 a high pressure helium repurification system, capable of purifying in a given time about 10 times more helium gas than the earlier low pressure

system. At about the same time a chilled water cooling system from the central air-conditioning plant was made available which made it possible to run the nitrogen plant continuously with operators working in three shifts. With this, enough liquid nitrogen is produced to meet the requirements of the whole Institute as well as for running the liquid helium plant and the high pressure repurifier.

The personnel of the plants have gained enough experience to deal with any kind of breakdowns of both the plants.

A helium leak detector is available to the experimental groups of the Institute for testing high vacuum systems, metallic cryostats, etc.

Liquid helium has been supplied for use in the following experiments carried out at the Institute and at BARC:

1. Nuclear Orientation
2. Superfluid helium flow experiments
3. Four groups working on Mössbauer effect
4. Ultrasonic attenuation in superconductors
5. Nuclear Magnetic Resonance
6. Electron Paramagnetic Resonance

and 7. Neutron Diffraction Studies at BARC.

It is planned to liquefy larger quantities of helium and store it in several 25-litre containers so that liquid helium can be made available to any experimental group any time that it needs. A proposal to utlize this group for development of cryogenic and superconducting technology is under consideration.

ELECTRON MICROSCOPE AND X-RAY UNIT

The Institute has a Philips EM 200 Electron Microscope capable of a resolution of 8 A and a magnification of 200,000 X. This is one of the best instruments available at present for investigating biological and metallurgical specimens. The laboratory has also set up facilities for shadow casting, vacuum evaporation etc. Two X-ray diffraction units (Philips PW 1009 and Siemens Crystalloflex IV) are available for crystallographic work. These facilities were installed in 1967 since it was found that they were needed on a regular basis for research in the Chemical Physics, Solid State Physics, Geophysics and Molecular Biology Groups of the Institute. They are therefore run as a general Institute facility. In addition to these groups in the Institute, several research institutions and universites in India have been making extensive use of these facilities

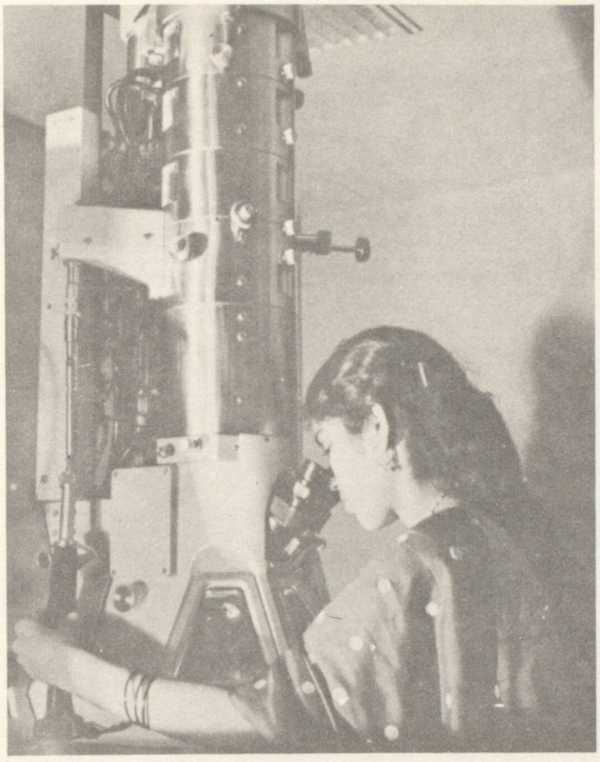


Fig. 2—Phillips EM-200 Electron Microscope which is available as a general facility. It has been used for studies covering a variety of topics such as cancer cells and DNA molecules to fission tracks in plastics.

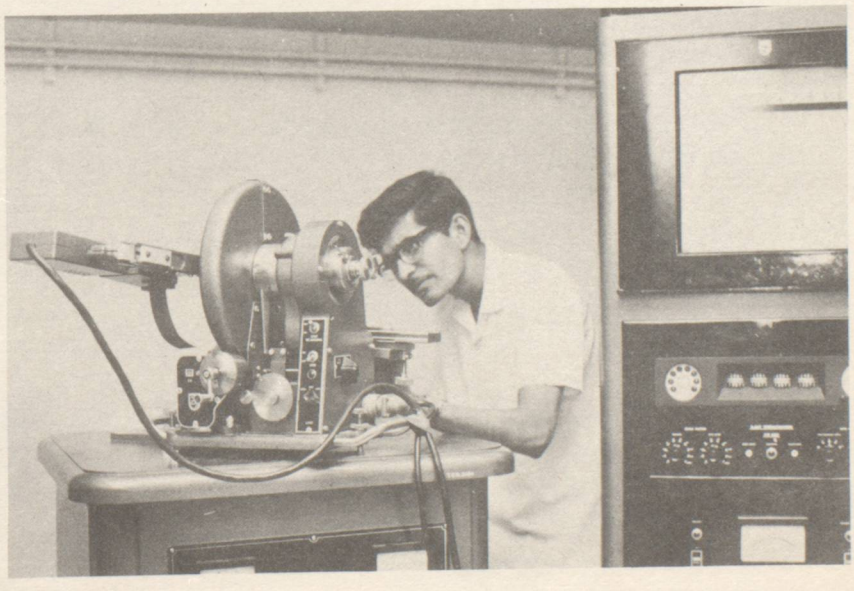


Fig. 3—X-ray diffractometer for structural investigations of inorganic compounds.

IRRADIATION FACILITIES

Ionising radiations such as fast electrons, gamma rays and X-rays produce a variety of effects in passing through matter. Studies of the solid state damage produced by them are of great interest to solid state physicists and materials technologists. Their use for sterilization of food and of surgical instruments is of interest to biologists, food technologists and medical scientists. And there are many phenomena of importance in radiation chemistry, biology etc. In view of the wide range of these phenomena and their implications, the Institute has set up irradiation facilities for general use by all interested groups. Two sources of radiation are available:

(a) 3.5 MeV Linear Electron Accelerator
and (b) 3000-Curie Co^{60} source.

3.5 MeV Linear Electron Accelerator

The Linear Electron Accelerator (LINEAC) is a pulsed source of fast electrons accelerated to an energy of 3.5 MeV. The maximum pulsed beam current available is 30 ma. The machine is housed in a specially shielded room to minimize radiation hazards to the operators and experimenters. This LINEAC was completely designed and fabricated at the Institute.

3000-Curie Co^{60} Source

A 3000-Curie Co^{60} source obtained from BARC, Trombay, is housed in a lead vessel designed and fabricated locally. Facilities have been provided for simultaneous irradiation at three ports, with doses which can be varied. A special interlocking system is used to ensure safe handling of the source.

EDUCATION AND TRAINING

The Tata Institute of Fundamental Research is permanently recognised by the University of Bombay as "a constituent recognised institution" for post-graduate research in physics, mathematics and molecular biology, under sections 52 and 56(2) of the Bombay University Act, 1953. In his letter dated 12th March, 1944, to the Sir Dorabji Tata Trust, in which he outlined his proposal for the setting up of an institute of fundamental research in Bombay, Homi Bhabha had stated:

"The Institute would be affiliated to the Bombay University". He believed that education and research must go hand in hand.

The Institute's primary objective has been to develop vigorous schools of research in mathematics, in fundamental physics, and in related areas of chemistry, life-sciences, electronics, engineering, etc. The attainment of this objective is clearly dependent on the quality and training of the research workers. Since the training generally available in India was considered inadequate for work in most modern areas of research, the Institute decided to have educational and training programmes of its own. These have been at the doctoral and post-doctoral level. The aim was to bridge the gap between the college and University training that was normally available, and creative research. In this section an account is given of the programmes of education and training in the School of Physics of the Institute.

Doctoral Programmes

A staff member can register himself at the University of Bombay, (as also at many other Universities in India), for a post-graduate degree by research, and work for this under the guidance of a scientist at the Institute who has been recognised by that University as a teacher for that degree. The Institute has about 133 staff members in the School of Physics at levels equivalent to University Professors and Readers; 42 of these are recognized by the University of Bombay for guiding students for the Ph.D. degree of the University.

89 Staff members have so far got their Ph.D. degree through the School of Physics of the Institute; and about 64 are currently working for their Ph.D. in physics. The number of Ph.D. theses from the Institute, which used to be only 2 or 3 per year until 1963, increased to around 5 in 1965, and has been about 10-12 per year since 1966. This number is constrained at present by the limited input of

junior research workers, which has been about 10 every year during the last few years; this in turn is determined by the staff requirements of the various research programmes.

The Institute's present character is that of a post-doctoral institution. All those who work and study at the Institute are paid staff members. At junior levels the appointments are made as Visiting Members, corresponding to reasonably high level studentships; and these are to enable a small number of very bright students, who come from all over the country, to work in the research programmes of the Institute for limited time periods and at the same time obtain their doctorates.

The Institute could easily increase, to double or more, the number of Ph.D.'s it trains every year, if it saw the need for it in terms of planned national requirements-e.g. if there was a phased national plan for the development of University departments and industrial activities, in which these scientists trained at the Institute could look forward to contributing meaningfully.

The Bombay University, like almost all other Universities in the country, does not have any course requirements for its Ph.D. students. Therefore, those working for the Ph.D. at the Institute did not have to take any formal courses in the early days. And it was also not possible, with the small numbe. of senior staff, to offer an integrated and full programme of courses. The Institute, however, has always had a number of lecture courses every year, some given by its own staff members and some by visiting foreign scientists. In the early years, courses by distinguished visiting scientists like Professors Alfven, Dirac, Pauli, Serber, Wentzel and many others filled part of the gap with regard to graduate courses.

As the Institute grew and the number of senior staff members increased, the number of courses that could be given also increased. And then, in order to make the Ph.D., training more systematic and broadbased, in 1964, a regular programme of graduate courses was started. These were optional in the beginning, but progressively have been made compulsory; and at present a staff member has to complete a certain number of graduate courses satisfactorily before being allowed to submit the thesis for a Ph.D. degree to a University. About 15 graduate courses have been planned for the current academic year. The training provided is as good as any available elsewhere in the world.

The Institute's role in the training of personnel for the Atomic Energy Programme

Homi Bhabha's letter to Sir Sorab Saklatvala, quoted earlier, contained the sentence:

> "Moreover, when nuclear energy has been successfully applied for power production, in say a couple of decades from now, India will not have to look abroad for its experts but will find them ready at hand".

Thus training of personnel for an eventual atomic energy programme was one of the functions of the Institute, already envisaged by Dr. Bhabha in 1944. Again in

his speech on January 15, 1962, at the inauguration of the new buildings of the Institute in Colaba by Prime Minister Jawaharlal Nehru, Homi Bhabha said:

> "The Atomic Energy Commission of the Government of India was first established in 1948, and one of its immediate problems was the shortage of scientific personnel in its field. It was, therefore, natural that the Commission should turn to the Institute for training personnel for its work and for carrying out some of its own major projects. ..... It is not an exaggeration to say that this Institute was the cradle of the atomic energy programme, and if the Atomic Energy Establishment Trombay* has been able to develop so fast, it is due to the assisted take-off which was given to it by the Institute in the early stages of its development. It is equally true to say that the Institute could not have developed to its present size and importance, but for the support it has received from the Government of India."

The Institute's contribution to the atomic energy programme** was two-fold. It provided personnel on a short-term as well as long-term basis. Many of the present group-leaders at Trombay started their research career at the Institute as students or as staff members. For example, the entire Reactor Theory Group was essentially a part of the Theoretical Physics Group of the Institute until 1960; the Electronics Group and Technical Physics Division at BARC had their origins in corresponding groups that had been set up and were functioning at the Institute. Secondly, Institute staff members participated quite substantially both in planning the course programme; and in lecturing, in the early stages of the BARC Training School; this school admits trainees from all over India after a very rigorous selection; training is then given for one year at a post-M.Sc. level in the areas of physics, chemistry, metallurgy, and electrical/mechanical/chemical/electronic engineering. Participation by the Institute in this training programme has progressively decreased, as the various groups at BARC have grown and been able to take increasing responsibilities themselves. The BARC Training School in its turn has provided the Institute with a very large number of bright research students, now on its staff.

M. Sc. Programme at Bombay University

One of the reasons for the location of the Institute in Bombay was the interest of the then Government of Bombay, which was anxious to build up a strong department of physics at the Institute of Science, and which had invited Homi Bhabha to undertake the task. In spite of this fact, the immense potentiality of the Institute (and BARC) for furthering the aims of higher education at the Bombay University have remained largely unutilized; though over the past few years there have been significant improvements in this matter. This has been essentially due to an unfortunate drawback of the affiliating system, where post-graduate education is a responsibility of all the colleges together, and therefore of no one in particular, unless the system can throw up a leader who will carry his colleagues in other colleges with him. The Institute has been deeply concerned about this

*Now Bhabha Atomic Research Centre (BARC)

**Additionally, the Institute contributed to building some of the hardware, e.g. the control system of India's first nuclear reactor, Apsara, was built under the auspices of the Institute in a war-time hutment on the Colaba site, and many parts of that reactor in the Institute's Workshop.

and there have been extensive discussions over the past three years with the college teachers who have also been anxious for a new look and a sense of dynamism. An intensified course programme for M.Sc. (Physics), and a review of the M.Sc. (Physics) syllabus to including significant experimental programme have been effected. Several members of the staff of the Institute now take courses on a regular basis for the M.Sc. students of the University. A University Department of Physics is now being set up and a senior scientist from the Institute has been appointed as Professor.

College Improvement Programme at Bombay University

Though the Institute staff members have been taking part in teaching M.Sc. classes in physics of the Bombay University, it is clear that in the long run the upgrading of the physics teaching at the M.Sc. level, and more so at undergraduate levels will have to depend on the colleges. Some of the senior teachers in the colleges have been very seriously interested in introducing changes, to learn and to take part in new developments, though they have in general felt helpless before the system. Some Institute staff members have therefore been involved in various attempts to help the colleges to help themselves. This programme is very recent, and some of the aspects involved are covered in the sections below; the experience so far has been quite encouraging.

Development of the College Laboratories

An interesting programme for improving the M.Sc. Nuclear Physics laboratory of a local college has been going on for over a year now. In this programme, one of the senior staff members of the Institute has been going regularly to this college, and some students from this college have been visiting the Institute laboratories from time to time; and a young enthusiastic lecturer from that college spent the recent summer vacation at the Institute. Recently, the University Grants Commission has helped this programme by sanctioning a substantial grant for the laboratory. This example can be and will be repeated in other colleges, if there is a certain minimum amount of local initiative. It is worth emphasizing that this has entirely been a voluntary effort, which has succeeded because of the goodwill and co-operation between the staff of the college and some of the Institute staff.

An in-service Refresher Programme for College Teachers

Since June 1969, some members of the Institute have been conducting a reading-cum-discussion programme for local college teachers. The group has been meeting quite regularly during term-time, once a week in the evening, for about two hours at the Institute. All teachers in the local colleges were invited to participate, and about 10 teachers have shown a sustained interest throughout the year. Many of them travel 10-15 miles, after a long day's work, to participate in this programme at the Institute; it certainly needs a considerable amount of motivation to do this. One of the aims of this programme has been to seek out the more motivated teachers, to plan other programmes for them, (e.g. next paragraph), and to try to start a multiplicative process through them.

This programme, again, has been based entirely on voluntary effort.

Programme for Selected Individual College Teachers

Apart from the above group programme, there is also a programme directed at individual motivated teachers. This can take various forms such as: (i) a teacher from a local college spending an extended period at the Institute to carry out research usually leading to a Ph.D. degree perhaps whilst continuing to work at his College on a limited basis; (ii) teachers spending their vacation periods at the Institute; and (iii) teachers carrying out advanced studies and research under the guidance of a scientist of the Institute, while still remaining at their colleges. Each of these has been tried out on a small scale with encouraging results.

These programmes for college teachers are now to be intensified with the help of the University Grants Commission. It is planned that several teachers every year will take a sabbatical year off from their respective colleges, and spend it at the Institute. These teachers would then get not only a refresher programme while they are at the Institute, but also establish continuing links with the Institute. The latter would be of help for the development of laboratories and curricula when they go back to their colleges.

Programme for Bright Undergraduate Students

This is another voluntary effort that has been going on for over two years. It takes the form of a discussion group, consisting of about 10 undergraduate students from different colleges who come to the Institute once in a fortnight. The Feynman lectures are used as part of the material around which discussions take place, and the students are encouraged to solve problems. Some of the students who participated in the programme in the first two years have now started a discussion group in their own college.

Relationships with other institutions of higher education in the Country

The Institute has taken the viewpoint that it is a major scientific facility created by the nation. Accordingly, it has always welcomed teachers and research workers from other universities and institutions of higher learning in the country to work here and to utilise the facilities available here. There has been an increasing number of such visits especially in the vacation periods. Some of these visitors come on their own whilst many have been supported by the Institute. Funds from the University Grants Commission are now starting to become available to enable the Institute to support such visits on a larger scale. Facilities that are extensively made use of by the visitors are: the National Computation Centre, the spectrometers and other equipment in the Chemical, Solid State, and Nuclear Physics Groups, facilities in the Geophysics Group and the Library. In reverse, staff members of the Institute have spent both short and long periods of time at the various institutions of higher education in the country to give seminars and lecture courses. There are also several research programmes of the Institute that are being carried out in collaboration with groups in universities in the country.

Summer Programme for Science Talent Scholars

Every year the Institute accepts a large batch of national science talent scholars who spend several weeks undergoing training here. Carefully tailored programmes are worked out to enable these students to derive the maximum benefit. These programmes include lectures on subjects at the frontiers of present

day knowledge, the opportunity of carrying out themselves experiments of an advanced nature, and participating in actual research activities of some of the groups.

Summer Schools

Each year Summer Schools are organized, in areas of direct interest to the Institute, in which research is being carried out at the Institute and in which significant advances have recently taken place. These summer schools are open to interested research workers in the country and in all cases where necessary, financial support is provided by the Institute. This programme has been conducted since summer of 1961. The courses given at the Summer Schools have been brought out in the Lecture Notes series of the Institute. These schools have played an important role in research activities at the Institute as well as in the country.

Programmes relating to Science Education in Schools

As the Institute matured over the years there was a growing realisation among the staff members that they should interact with society in as many areas of mutual interest as possible. One of these areas of vital national importance is Science Education, both at the student and at the public level. It was felt that, in addition to programmes relating to education at the University level in which the Institute was engaged, Institute scientists should concern themselves with the improvement of science teaching at the schools and help in developing the habit of 'learning through experiments'.

A start was made with a programme of lectures and lecture-demonstrations for students at a few local schools arranged in cooperation with the concerned teachers of science. In association with the Bombay Municipal Corporation, a start was also made with a teacher-training workshop and in arranging annual Interschool Science Exhibitions; these have been arranged twice, in February 1970 and February 1971 and have involved about 50 schools. These have been very successful.

Improvements in the teaching of science at the school level have to be carried out by the teachers themselves. Institute scientists are aware that they are not experts in this area; they can only provide administrative support and scientific expertise, and contribute by interacting with those actually engaged in teaching. Accordingly, monthly seminars have been arranged at which teaching aids and teaching methodology are discussed. For students there are monthly lecture demonstration conducted at the Institute; these lecture demonstrations have been very popular. Ways and means to use the Homi Bhabha Auditorium for this purpose are being explored in order to cater to much larger numbers.

A workshop for Municipal School teachers was conducted in 1970; this was to train teachers to adopt material recently developed by the Physics Study Group of the All India Science Teachers' Association; an Institute scientist has translated the teacher's guide into Marathi for local use. A follow-up of the trained teachers, as well as the training of teachers with additional material developed by the same

group, will continue. The enthusiasm generated among the school teachers has been heart warming.

It is worth emphasising that this entire programme, relating to science education in schools, has been conducted by staff members on a voluntary basis, the motivation being the sense of responsibility they feel with regard to the society around.

Concluding Remarks

In this section an attempt has been made to bring out the efforts by the Institute on an official basis, and by many staff members on a voluntary basis to contribute to the system of education at all levels in the city and in the country. Much of this is of recent origin and covers a period over the past few years. There are many other aspects which are as yet in the planning stage which have not been mentioned in this. It is recognized that the education and research go hand in hand, and it is hoped that through these efforts, research at the Institute will be meaningfully coupled with the educational system.

CONFERENCES AND MEETINGS ORGANISED BY THE SCHOOL OF PHYSICS

International Conferences

The International Conference on "Elementary Particles" Bombay, December 4-22, 1950.

The International Conference on "Cosmic Rays" Jaipur, December 2-14, 1963.

Symposia, Colloquia etc.

Seminar on "Implementation of Microelectronic Technology" Bombay, December 5-10, 1966.

An Intensive Tutorial Programme on "Computer Based Linguistic Studies" Bombay, June 3-15, 1968.

Colloquium on "Cosmic Ray Studies in Relation to Recent Developments in Astronomy and Astrophysics" Bombay, November 11-16, 1968.

International Training Course on "Microbial Physiology and Genetics in Molecular Biology" Bombay, November 24—December 6, 1969.

Seminar on "Visual Mechanisms and Form Perception" Bombay, January 25—February 6, 1971.

Summer Course for Students of The National Talent Search Scheme

Summer Course for Students of the National Talents Search Scheme Organised at the TIFR, May 7—June 5, 1968.

Summer Course for Students of the National Talents Search Scheme Organised at the TIFR, May 12—June 10, 1969.

Summer Course for Students of the National Talents Search Scheme Organised at the TIFR, May 18—June 16, 1970.

Summer Schools etc.

Title of the Summer School	Names of the Lecturers	Place & Year
Summer School in Theoretical Physics	Prof. R.H. Dalitz Prof. M. Gell-Mann	Bangalore, 1961
Summer School in Theoretical Physics	Prof. R.H. Dalitz Prof. S. Frautchi	Bangalore, 1962
Summer School in Theoretical Physics	Prof. J.J. Sakurai Prof. L. Mitchel Prof. A.N. Tavkhelidze	Bangalore, 1963

Title of the Summer School	Name of the Lecturers	Place & Year
Summer School in Theoretical Physics	Prof. F.E. Low Prof. D. Amati	Bangalore, 1964
Summer School in Nuclear Spectroscopy	Prof. B.R. Mottelson Prof. I. Talmi Prof. C.A. Levinson	Bangalore, 1964
Summer School in Magnetic Resonance & Solid State Physics	Prof. E.L. Hahn Prof. K.W.H. Stevens	Nainital, 1965
Summer School in Nuclear Structure & Nuclear Reactions	Prof. J.B. Blair Prof. C.F. Clement Prof. Shiro Yoshida	Bangalore, 1965
Summer School Theoretical Physics	Prof. R.H. Capps Prof. K. Johnson	Bangalore, 1965
Summer School in Mössbauer Effect	Prof. J.F. Duncan Prof. K.S. Singwi	Bangalore, 1966
Summer School in Relativistic Astrophysics & Cosmology	Prof. G.R. Burbidge Prof. (Mrs.) E.M. Burbidge Prof. D.W. Sciama	Bangalore, 1966
Summer School in Coding Theory & Graph Theory	Prof. C. Berge Prof. R.C. Bose	Bombay, 1966
Summer School in Solid State Physics	Prof. M. Balkanski Prof. R.J. Elliott Prof. S. Ramaseshan	Bangalore, 1967
Summer School in Switching Theory & Automata Theory	Prof. Juriz Hartmanis Dr. William H. Kautz	Bombay, 1967
Winter School in Molecular Biology	Prof. Maurice S. Fox Prof. Alan Garen Prof. Martin Gellert	Bombay, 1967
Summer School in Nuclear Structure & Nuclear Reactions	Prof. V. Gillet Prof. D. Robson	Bangalore, 1968
Summer School in Physics of Condensed Matter	Prof. K.S. Singwi Prof. A.T. Stewart	Bangalore, 1969
Summer School in Theoretical Physics	Prof. G.F. Chew Prof. F.E. Low	Nainital, 1969
Summer School in Ligand Field Theory	Prof. C.J. Ballhausen Prof. B.R. Judd	Bangalore, 1970
Summer School in Nuclear Structure & Nuclear Reactions	Prof. N. Austern Prof. D.M. Brink	Bangalore, 1970

OTHER PUBLICATIONS FROM THE SCHOOL OF PHYSICS

Proceedings of Conferences

Proceedings of the International Conference on Elementary Particles, Bombay Dec 14-22, 1950.

Proceedings of the Eighth International Conference on Cosmic Rays, Jaipur Dec 2-14, 1963 (in Six Volumes).

Proceedings of the Colloquium on Cosmic Ray Studies in relation to recent developments in Astronomy and Astrophysics, Bombay, Nov 11-16, 1968.

Studies in Physics

DALITZ, R.H. : Strange Particles and Strong Interactions (Published in the series *"Studies in Physics"* distributed by Oxfored University Press, price Rs. 19/-).

DALITZ, R.H. : Nuclear Interactions of the Hyperons (Printed at Commercial Printing Press and distributed by Oxford University Press as a second title in the series *"Studies in Physics"*.

Frontiers in Physics

FRAUTSCHI, S. : Regge Poles and S-Matrix Theory (Published for the Institute by W.A. Benjamin, Inc., New York in the *"Frontiers in Physics"* series, price $ 4.95).

Lecture Notes on Physics

DIRAC, P.A.M. : On Quantum Mechanics and Relativistic Field Theory, 1955.

WENTZEL, G. : On Special Topics in Quantum Mechanics, 1956.

WENTZEL, G. : On Special Topics in Field Theory, 1957.

SERBER, R. : On Parity, Charge Conjugation and Time Reversal, 1957.

SERBER, R. : On High Energy Nuclear Reactions, 1957.

ALFVEN, H. : On Magnetohydrodynamics and Cosmic Rays, 1958.

DALLAPORTA, N. : On Strong Interactions of Strange Particles and their Symmetries, 1959.

LAMB, W.E. : On Mossbauer Effect, 1960.

HEITLER, W. : On Problems Connected with the Finite Size of Elementary Particles, 1961.

GELL-MANN, M. : On Weak Interactions of Strongly Interacting Particles, 1963.

DALITZ, R.H. : On the Properties and the Symmetry Theories of the Resonant States, 1963.

LAMB, W.E. : On Masers, 1964.

BLOCH, C. : On Nuclear Many-Body Problem, 1964.

TAKAGI, S. : On the Many-Body Problem, 1964.

SAKURAI, J.J. : On New Mesons, Resonances and Unitary Symmetry, 1964.

TAKAGI, S. : On Extensive Air Showers and High Energy Interactions, 1964.

TAVKHELIDZE, A.M. : On Quasipotential Method in Field Theory, 1964.

LOW, F.E. : On Elementary Particles and Scattering Theory, 1964.

LEVINSON, C.A. : On Hartree-Fock Theory and its Applications to Nuclei, 1964.

MOTTELSON, B.R. : On Selected Topics in Nuclear Structure, 1964.

TALMI, L. : On Shell Model Spectra in Nuclei, 1964.

CAPRIZ, G. : On Numerical Analysis and Linear Programming, 1965.

GORTER, C.J. : On Magnetism and Superconductivity, 1965.

STEFFEN, R.M. : On Angular Correlation of Nuclear Radiations, 1965.

CAPPS, R.H. : On Nonelementary Particles, 1966.

BALAZS, L.A.B.	: On Bootstraps, 1966.
BLAIR, J.S.	: On Reactions with Strongly Absorbed Particles, 1966.
CLEMENT, C.F.	: On Formal Reaction Theories and their Physical Consequences, 1966.
YOSHIDA, S.	: On Stripping and Pick Up Reactions and their Application to Nuclear Spectroscopy, 1966.
BERGE, C.	: On Graph Theory, 1967.
BOSE, R.C.	: On Goding Theory, 1967.
SCIAMA, D.W.	: On Observational Cosmology, 1967.
SINGWI, K.S.	: On Principles and Applications of Mossbauer Effect, 1967.
BURBDIGE, G.R.	: On high Energy Astrophysics, 1967.
HARTMANIS, J.	: On Automata Theory, 1968.
KAUTZ, W.H.	: On Switching Theory, 1968.
BURBIDGE, E.M.	: On Radio Galaxies and Quasi-Steller Objects, 1968.
DUCAN, J.F.	: On Chemical Applications of Mossbauer Efect, 1968.
BALKANSKI, M.	: On Band Structures of Semiconductors, 1969.
ELLIOTT, R.J.	: On Theory of Magnetism, 1970.
LOW, F.E.	: On Weak Interactions, 1970.

VISITING SCIENTISTS IN THE SCHOOL OF PHYSICS

1947	BLACKETT, P.M.S.	U.K.
	MAJUMDAR, R.C.	India
1948	VALLARTA, M.S.	Mexico
1950	KANDIAH, K.	Ceylon
	PETERS, B.	U.S.A.
	WENTZEL, G.	U.S.A.
1951	ROSENFELD, L.	U.K.
	SALVETTI, C.	Italy
1952	PAULI, W.	Switzerland
1953	BLACKETT, P.M.S.	U.K.
	COCKROFT, J.D.	U.K.
	LEVI, M.	France
	MAYER, J.E.	U.S.A.
	MAYER, M.G. (Mrs.)	U.S.A.
	MARSHAK, R.E.	U.S.A.
	SALAM, A.	Pakistan
1954	DIRAC, P.A.M.	U.K.
1955	OLIPHANT, MARCUS	Australia
	TOMONAGA, S.	Japan
1956	POWELL, C.F.	U.K.
	WENTZEL, G.	U.S.A.
1957	ALFVEN, H.	Sweden
	SERBER, R.	U.S.A.
	VAINU BAPPU, M.	India
1958	BLACKETT, P.M.S.	U.K.
1959	DALLAPORTA, N.	Italy
	TSUZIKI, Y.	Japan
1960	GAMOW, G.	U.S.A.
	HEITLER, W.	Switzerland
	LAMB, W.E.	U.S.A.
	MIYAKE, S.	Japan
	NIELS BOHR	Denmark
	SUESS, H.E.	U.S.A.
1961	FOWLER, P.H.	U.K.
	LOW, W.	U.S.A.
	PETERS, B.	Denmark

1962	ARNOLD, J.R.	U.S.A.
	BLACKETT, P.M.S.	U.K.
	BLOCH, C.	France
	BLOCH, FELIX	U.S.A.
	BOK, B.J.	Australia
	COSTAIN, C.C.	Canada
	DAYTON, B.	U.S.A.
	ERIKSSON, E.	U.S.A.
	FUJIMOTO, Y.	Japan
	GRIVET, P.	France
	HINOTANI, K.	Japan
	LEE, T.D.	U.S.A.
	LOCK, W.O.	Switzerland
	MATANO, T.	Japan
	MIYAKE, S.	Japan
	MULLER, D.E.	U.S.A.
	NEEL, L.	France
	ROBERTS, M.	Switzerland
	ROBINSON, A.	U.S.A.
	ROSENBLITH, W.A.	U.S.A.
	TAKAGI, S.	Japan
	TAMM, I.E.	U.S.S.R.
	TAYLOR, H.J.	India
	UREY, H.C.	U.S.A.
	WENTZEL, G.	U.S.A.
1963	FEINBERG, G.	U.S.A.
	GORTER, C.J.	Netherland
	KASTLER, A.	France
	KURT SITTE	Germany
	MARSHAK, R.E.	U.S.A.
	MIYAKE, S.	Japan
	MORAVCSIK, M.J.	U.S.A.
	ROSENFELD, L.	Denmark
	SCHIFF, L.I.	U.S.A.
1964	BALAZS, L.A.P.	U.S.A.
	CAPRIZ, G.	Italy
	KAMIYA, Y.	Japan
	MIYAKE, S.	Japan
	MATANO, T.	Japan
	SARABHAI, A.S.	U.K.
	TOVEY, S.N.	U.K.
1965	BINFORD, T.	U.S.A.
	HENRY HIZ	U.S.A.
	ITO, N.	Japan
	KURN, D.M.	U.S.A.
	MacKEOWN, P.K.	U.K.
	MOHLING, F.	U.S.A.
	NAKANO, T.	Japan
	O'CEALLAIGH, C.	Ireland
	PATTISON, J.B.M.	U.K.
	PETERS, B.	Denmark
	PRICE, P.B.	U.S.A.
	STEFFEN, R.M.	U.S.A.
	WENTZEL, G.	U.S.A.
	WOLFENDALE, A.W.	U.K.

1966	FRAUTSCHI, S.	U.S.A.
	GOLDANSKII, V.I.	U.S.S.R.
	HINOTANI, K.	Japan
	PATI, J.C.	U.S.A.
1967	AEGERTER, S.	Switzerland
	MIYAKE, S.	Japan
	OPPENHEIM, A.B.	Israel
	RASZILLIER, I.	Rumania
	ZACHARIASEN, F.	U.S.A.
1968	CAMERON, A.G.W.	U.S.A.
	FOWLER, W.A.	U.S.A.
	FRAUTSCHI, S.C.	U.S.A.
	GOLDBERG, E.D.	U.S.A.
	HAYAKAWA, S.	Japan
	JACOB, T.M.	U.S.A.
	LINGENFELTER, R.E.	U.S.A.
	McCREA, W.H.	U.K.
	MISTRY, N.B.	U.S.A.
	PARKER, E.N.	U.S.A.
	PETERS, B.	Denmark
	POWELL, C.F.	U.K.
	ROSSI, B.	U.S.A.
	SHAKESHAFT, J.	U.K.
	VAN DE HULST, H.G.	Netherlands
	VAINU BAPPU, M.	India
	YODH, G.B.	U.S.A.
1969	FRED HOYLE	U.K.
	HANS BETHE	U.S.A.
	HESTENES, M.R.	U.S.A.
	IRANI, K.B.	U.S.A.
	MENDELSSOHN, K.	U.K.
	NARASIMHAN, P.T.	India
	NARLIKAR, J.V.	U.K.
1970	AGASHE, S.D.	U.S.S.R.
	ANDERSEN, J.U.	Denmark
	ARRHENIUS, G.	U.S.A.
	BALACHANDRAN, A.P.	U.S.A.
	FELTEN, J.E.	U.K.
	GAGARINSKI, Y.V.	U.S.S.R.
	HANSEN, P.G.	Denmark
	LINDSTROM, R.M.	U.S.A.
	MAKINO, F.	Japan
	MIYAKE, S.	Japan
	PAKVASA, S.	U.S.A.
	RASIWALA, M.M.	France
	SCHULMAN, J.H.	U.S.A.
	SRIVASTAVA, B.N.	India

GENERAL INSTITUTE FACILITIES

THE LIBRARY

The Library started functioning in 1946 with an initial collection of about 300 volumes, mainly in the areas of Mathematics and Cosmic Rays. With the widening of research activities and interests in the Institute, the holdings of the Library have rapidly expanded and to-day it covers literature on Astronomy, Astrophysics and Space Sciences, Theoretical Physics including Elementary Particles, Low and High Energy Nuclear Physics and Solid State Physics, major aspects of Nuclear Sciences like Nuclear Spectroscopy, Nuclear Reactions and Nuclear Magnetic Resonance, Planetary Sciences, Computer Sciences including Computer based Linguistics and Behavioural Studies, Electronics including Microwave Engineering, and Molecular Biology.

In the beginning Professor F. W. Levy was Professor-in-Charge of the Library. In 1953, a Library Committee was formed under the Chairmanship of the then Director, Dr. H. J. Bhabha. The following year, Dr. M. B. Vajifdar joined the Library as its head and this can be said to be the point from which the Library was structured scientifically to grow on modern professional lines. In 1959, a new Library Committee was formed, under the Chairmanship of Professor K. Chandrasekharan; this Committee framed the basic rules under which the Library has since then been operating.

During the sixties there has been a steady all round progress in the Library. While in 1960, the annual acquisition was around 2,000 volumes, it rose to 3,600 by the end of the decade. By January 1971, the Library's holdings comprised 42,000 volumes; it also receives more than 800 periodicals. Additionally, it has an extensive collection of reports, reprints, translated papers and theses. Some of these are in microforms and facilities exist for reading the same.

In addition to the main Library in the Institute in Bombay, there are separate collections of books and journals at Ootacamund to serve the needs of the Radio Astronomy Centre and of the Cosmic Ray Laboratory. Although the Library's primary function is to serve the Institute, it has always been available as a reference centre for personnel from the Bhabha Atomic Research Centre.

Acquisition of Books

The Library has entered into a Library-Dealer Plan, with several of the leading publishers abroad, whereby it automatically receives on publication, new books

of interest to the Institute on an approval basis. The Library makes use of the computer facilities at the Institute for processing book orders. Routine scanning of current journals and book announcement lists and pamphlets received from the book trade, is also regularly carried out to ensure that the acquisition is complete.

New books are displayed for 10 days. A monthly list of recent additions is published without delay. Readers can register their claim for new books, while these are on display.

Books are classified according to the Universal Decimal Classification system. However, Mathematics books are classified according to a scheme adopted by the School of Mathematics. With regard to cataloguing, the Library maintains the various conventional catalogues under heads such as Author, Subjects, Series, etc. The subject catalogue is in the form of strips, thereby affording the readers a quick glance over all the material on a given topic. For conference proceedings, the cataloguing is rather extensive; one can find an entry, even under the place, where the conference was held.

It takes between 10 and 16 weeks for a current journal to arrive from abroad by surface mail. The Library, therefore, receives some of the essential journals by direct air mail. Since the number of such journals which need to be received without much delay is rather large, the Library has made special arrangements to air-lift them in bulk. Current numbers are collected by a central agency at Amsterdam and then sent to Bombay by air-freight, every week. By this, it has been possible to reduce the transit period to three weeks only.

Journals

Current journals on display bear a triangular strip for the first 15 days of their arrival. A select list of new arrivals of journal numbers is also put up every day.

Besides books and journals, the Library endeavours to obtain preprints, journal articles and reports by air mail. This material is displayed every Monday and a weekly list of the same is sent to various institutions and universities in India. It thus serves as a national source of information for the latest research in areas in which work is being carried out at the Institute.

The Library has arrangements with organizations like NASA, IAEA, University Microfilms Inc., U.S. Clearing House for Federal Scientific and Technical Information and Institute for Scientific Information, for getting on request any literature relating to the latest research on topics of interest to Scientists in the Institute.

The Library participates in the interlending service with other libraries in Bombay and elsewhere in India. Any material not available in the TIFR collection can normally be obtained within hours on a loan basis. For this purpose the Library has maintained a Union Catalogue of periodical holdings in the various local libraries. The Library supplies, when needed, photocopies of research papers to the Institute Staff.

Circulation The Library is run on an open-access basis. Volumes can be borrowed quickly since rules for borrowing are kept liberal. While books in Physics and allied subjects are expected to be returned within a month and journal volumes within a week, no such time limit has been placed in the case of volumes in Mathematics. Current journals are essentially treated as reference material. To facilitate borrowing, duplicate issues are obtained in the case of a few of the important journals. The only restriction on borrowers is that all the reading material should be back in the Library for annual stocktaking.

A list of subject headings of the book collection is given below:

Generalia
Philosophy of Science
Library/Information Science
Cybernetics
Psychology
Science-General
Mathematics
Statistics
Mathematical Logic
Fluid Mechanics
Mechanics of Gases
Hydrodynamics
Thermodynamics
Accoustics
Optics
Heat
Low Temperature Physics
Electricity and Magnetism
Cosmic Rays
X-Rays
Nuclear and Atomic Physics
Nuclear Instrumentation
Bubble Chamber
Nuclear Emulsions
Elementary Particles
Electron Spin Resonance
Nuclear Interactions
High Energy Physics
Nuclear Structure
Nuclear Magnetic Resonance
Radioactivity
Nuclear Reactions
Solid State Physics
Chemistry
Physical Chemistry
Analytical Chemistry
Applied Sciences/Technology
Workshop Practice
Management
Operations Research
Research and Development
Materials Science
Astronomy
Astrophysics
Cosmology
Radio Astronomy
Stellar Astronomy
Physics
Theoretical Physics
Quantum Theory/Mechanics
Statistical Mechanics
Inorganic Chemistry
Organic Chemistry
Crystallography
Earth Sciences
Geophysics
Geochemistry
Oceanography
Meteorology
Groundwater Hydrology
Biological Sciences
Genetics
Cytology
Microbiology
Biochemistry
Medical Sciences
Cancer
Electrical & Electronics Engineering
Control Theory
Circuit Theory
Microwave Engineering
Lasers and Masers
Transistors
Micro-Electronics
Accelerators
Communication Theory
Radio and Television
Astronautics
Computer Science/Arts
Fine Arts
Architecture
Photography
Linguistics

HOMI BHABHA AUDITORIUM

An Auditorium was part of the original building plans of the Tata Institute of Fundamental Research. But it was decided to take up the construction of the Auditorium only after the first phase of building activity was completed: that involving the laboratories, library, workshop, canteens, offices, etc.

The Institute, the Department of Atomic Energy, and the Bhabha Atomic Research Centre have organized in the past, at the Institute, international and national conferences and symposia, jointly with bodies such as the International Council of Scientific Unions, the International Mathematical Union, the International Atomic Energy Agency and so on. With the facilities available, (the largest of the lecture halls having only a capacity of 200 seats), these had to be on a small scale. For example, the rather large International Conference on Cosmic Rays under the auspices of the International Union of Pure and Applied Physics and the Department of Atomic Energy, had to be organized in Jaipur (in December 1963) where the Ravindra Bhavan was used as the venue.

The number of qualified scientists and engineers engaged in research and development activities of the Institute is now over 350; there are large numbers of scientific staff who possess degrees in science, and are additionally qualified in various technical areas; all of these would benefit from and enjoy general-purpose scientific programmes as can be arranged in a large auditorium. Further, the total staff strength of the Institute is over 1400. In view of numbers such as these, it was felt that it would be desirable to have an Auditorium with a capacity of around 1000, instead of the originally planned figure of 600.

Homi Bhabha felt that an Auditorium with a capacity of 1000 seats would not be used by the Institute throughout the year for its own scientific and educational activities alone. He thought, therefore, that it would be useful to plan the Auditorium such that it could also be used for cultural activities such as music, dance, drama and film shows; these might be arranged by the Institute, as well as by organizations under the administrative purview of the Department of Atomic Energy, in connection with conferences, etc. The auditorium could then be an amenity for the city since, when free, it could be made available on payment of appropriate charges to cultural organizations which may wish to put on activities as are approved by the Institute. To make this possible the original designs were altered by increasing the area of the stage, and by introducing a high loft to enable scenery to be stacked.

The Homi Bhabha Auditorium was inaugurated by Prime Minister Shrimati Indira Gandhi on 9th November, 1968, and has been in regular use since then. It is fully airconditioned and has a seating capacity of 1036 seats. It is equipped with a fully wired simultaneous translation facility which enables the use of the floor plus four other languages, which is essential for most international conferences today. Alternate chairs have concealed speakers fitted to their backs; and each

chair is fitted with a box, which has a key for selecting the required language, request and volume adjustments, and arrangements for headphones. These boxes are removeable; and are therefore fitted only when required for Conferences. In view of these technical requirements and the special design, the chairs were manufactured in the workshop of the Institute. The simultaneous translation facility and dimming system were designed and fabricated at the Electronics Division of the Bhabha Atomic Research Centre.

The stage has an area of 2400 sq. ft. with a proscenium opening of 40'x18' and has several drops and spot/flash lights. The drops are both electrically and mechanically operated. A shell for reflecting sound into the hall can be put on the stage for music performances in which the sound reinforcement system is not to be used. Storage facilities exist in the basement under the stage where four green rooms are also located. The green rooms are tastefully decorated and furnished. Facilities exist for projecting 35 mm films.

The Homi Bhabha Auditorium was designed by Mr. Helmuth Bartsch of M/s. Holabird and Root of Chicago. The overall responsibility for the construction of the Auditorium was that of the Building Project Group of the Institute, which had to do a great deal of detailing, both with regard to architectural and engineering drawings and the use of local materials.

Since it was commissioned, the Auditorium has been extensively used both by the Institute and by outside bodies for scientific lectures, conferences (national and international), programmes of vocal and instrumental music, dance and ballet performances, drama and film shows.

Attached to the Homi Bhabha Auditorium is a Museum area where the Institute can display, through photograph as well as by working equipment, some of the important results obtained at the Institute, as also elsewhere in the world. The Museum has an area of 6500 sq. ft. and is fitted with special railings for display of paintings.

The Auditorium has an open car park that can accommodate 380 cars.

There is increasing need to bring science closer to the people, as part of science education at all levels, and for developing scientific temper in the nation. The Institute hopes that the Homi Bhabha Auditorium and Museum areas will constitute an important interface of the Institute with the outside where, through regular programmes of lectures and exhibitions, it will be possible to convey to the public, particularly the younger generation on whom the future of the country depends, a picture of what is being done in the Institute and why, and thus carry science into society.

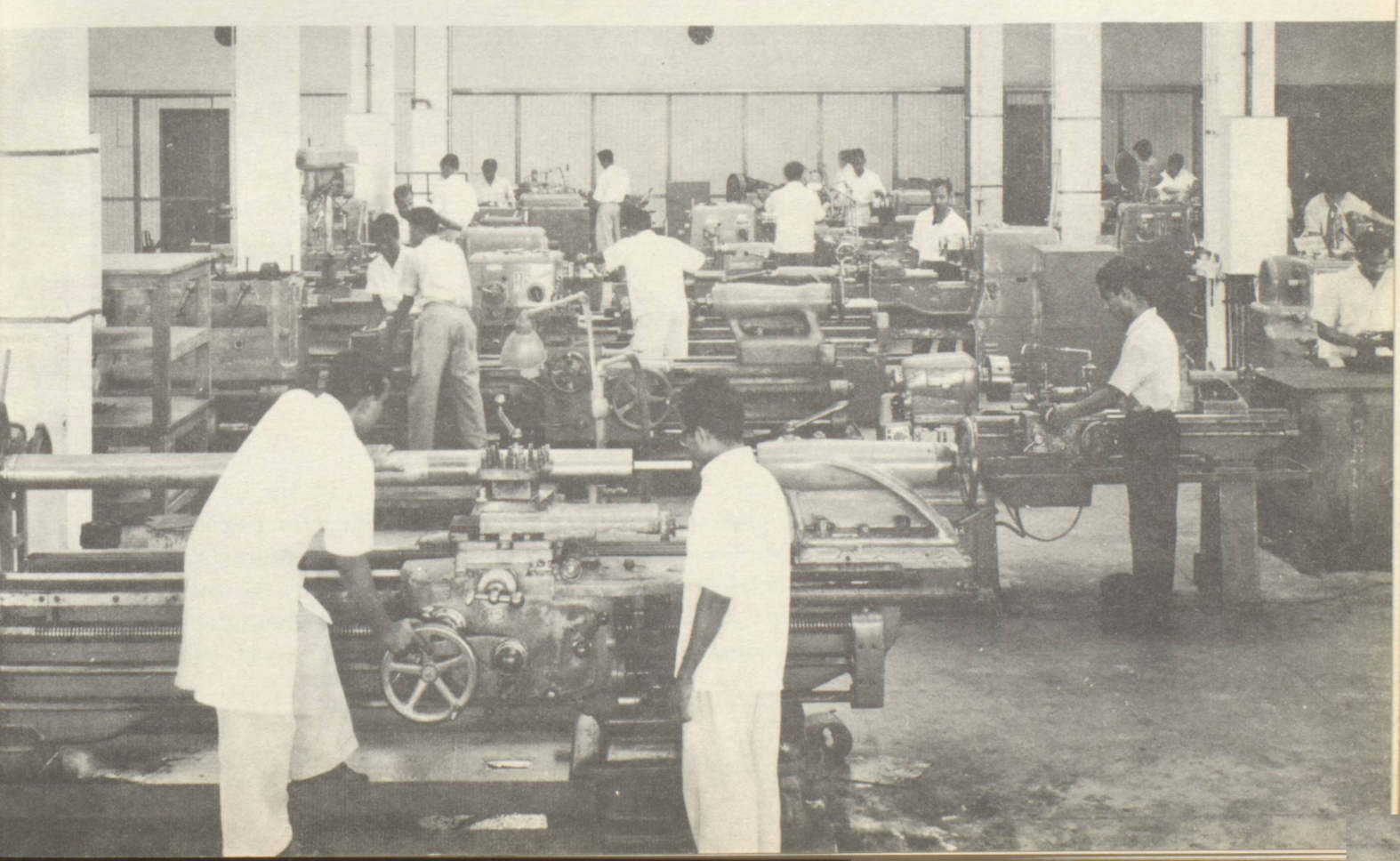
THE CENTRAL WORKSHOP

The Central Workshop had its beginning in July 1946 when the Institute was still in Kennilworth at Peddar road. At that time the workshop consisted of only a lathe and a drilling machine with two mechanics and a supervisor. As the Institute grew in size, more machines were added and when it moved to the Old Yacht Club at Apollo Pier the workshop became a major facility, with the addition of various types of lathes, milling machines, shaping machines, sheet cutting and bending machines. Welding and carpentry units were also added at the same time.

In 1961 the workshop moved into its present premises specifically designed and constructed for a versatile modern workshop facility. Large number of precision machines to meet the increased experimental activities were added.

In the early years the workshop played an important role in carrying out precision jobs for the group engaged in Cloud Chamber experiments. In addition to the fabrication of Cloud Chambers, special types of cameras

Fig. 1—A section of the workshop in the new premises.



were also made in the workshop. In the early attempts to develop the Van-de-graaff generator and the 12" cyclotron, several complicated and intricate mechanical parts were fabricated. The complete Control Desk and the panels of the first atomic reactor, "Apsara", were designed and made in the Institute workshop. Over the years the central workshop has to its credit the construction of major pieces of equipment such as intricate parts of the radio telescope at Ootacamund, glass blowing lathes, disc bonding machine for the micro-electronics group, field equipment for balloon facility at Hyderabad, the large multiplate cloud chamber for the extensive air shower project at Ootacamund. It is needless to say that the success of the experimental programmes in the Institute is largely due to the technical support provided by the workshop.

The workshop also undertook the responsibility of running an apprentice training programme for several years to train mechanics who could later be absorbed at the Institute as well as at the Atomic Energy Establishment, Trombay. The Trombay Establishment which was growing rapidly, needed well trained mechanics in large numbers and this requirement was met to a large extent by this training programme.

The Institute workshop has also rendered considerable service in fabricating several pieces of scientific equipment for the Cancer Research Centre, the Haffkine Institute, the University Department of Chemical Technology and the Indian Institute of Technology.

Drawing & Design Section

A design and drawing facility set up in early fifties, has grown along with the workshop. The main task of this facility is two fold (a) to make engineering drawings of the intricate parts of machines, new apparatus and equipment used in the scientific experiments, which are passed on to the workshop for execution of the jobs, (b) to carry out tracing work related to graphical representation of scientific data for publication purposes, as also the associated ammonia printing.

Photography Section

The Photography Section as a general facility started functioning in 1955 when a full-time professional photographer was employed by the Institute. The main function of the photographic section is to make slides for projection and prints for publications of scientific papers. In addition the photographic section provides large size enlargements for scientific exhibitions. In the early years wall size photographic murals and panoramic background photographs were produced in the photography section of the Institute for world exhibitions

in which the Department of Atomic Energy participated. A 16 mm colour documentary film entitled "TIFR—A Short History" was produced by the Photographic Section in connection with the Silver Jubilee celebrations of the Institute during 1970-71.

The TIFR Photographic Section has also trained technicians of other research institutions like the Physical Research Laboratory, Ahmedabad, and the Bhabha Atomic Research Centre.

Central Maintenance Services

During the early years the maintenance of the Institute buildings and the design of new constructions were carried out by the Architectural and Civil engineering division of the Atomic Energy Establishment. As the work load increased, particularly the maintenance of electrical and sanitory fittings and airconditioning plants, pump houses etc. a separate central services section was established in the Institute.

The central services over the years has executed a variety of major installation jobs such as:

1. Installation of CDC computer system with complete fabrication of electrical fixtures, airconditioning of computer area and associated civil work.
2. Electrification of the Homi Bhabha Auditorium.
3. Modification of central airconditioning plant.
4. Construction of a Clean Room for Solid State Electronics and additional Hutments for Microwave Engineering.

Shift duty personnel of the Central Services work round the clock and are available for any emergency.

THE GLASS SHOP AND PRECISION INSTRUMENTS

The glass blowing section is one of the oldest sections of the Institute. It started with just two glass blowers occupying a part of one of the four laboratory rooms in the ground floor of the Kennilworth building. The chief glass blower had his earlier training at the Indian Institute of Science, Bangalore. The indigenous inhouse production of the Geiger Muller counters by the glass blowing section gave a big boost to cosmic ray research in the Institute in the early days.

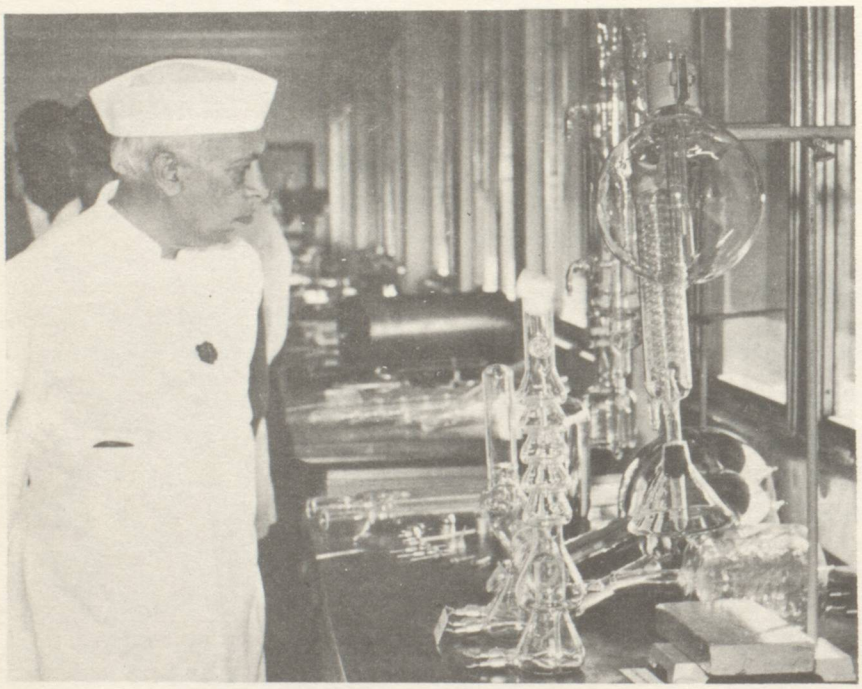


Fig. 1—The then Prime Minister, Jawaharlal Nehru observing some of the fascinating glass apparatus made by glass shop.

Some of the specialized jobs developed in the glass shop are Ozone source tubes, xenon flash tubes, various types of electronic tubes, vacuum contactors, liquid nitrogen and liquid hèlium cryostats. The neon flash tubes required for underground cosmic ray experiments at the Kolar Gold Fields were fabricated in large numbers by the glass shop.

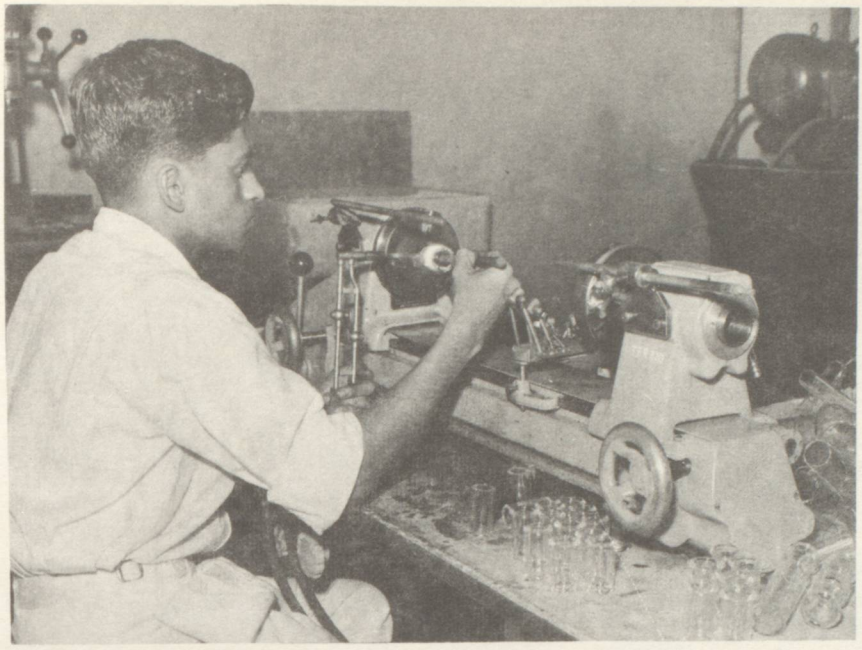


Fig. 2—A glass blower working at the glass blowing lathe.

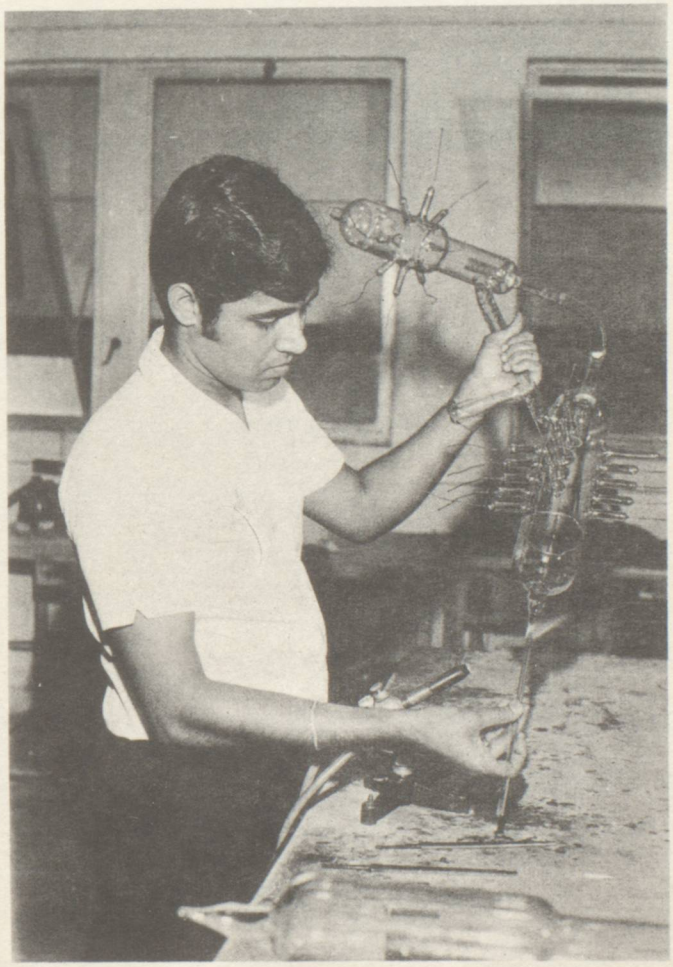


Fig 3—An expert glass blower giving the finishing touches to a mass spectrometer tube.

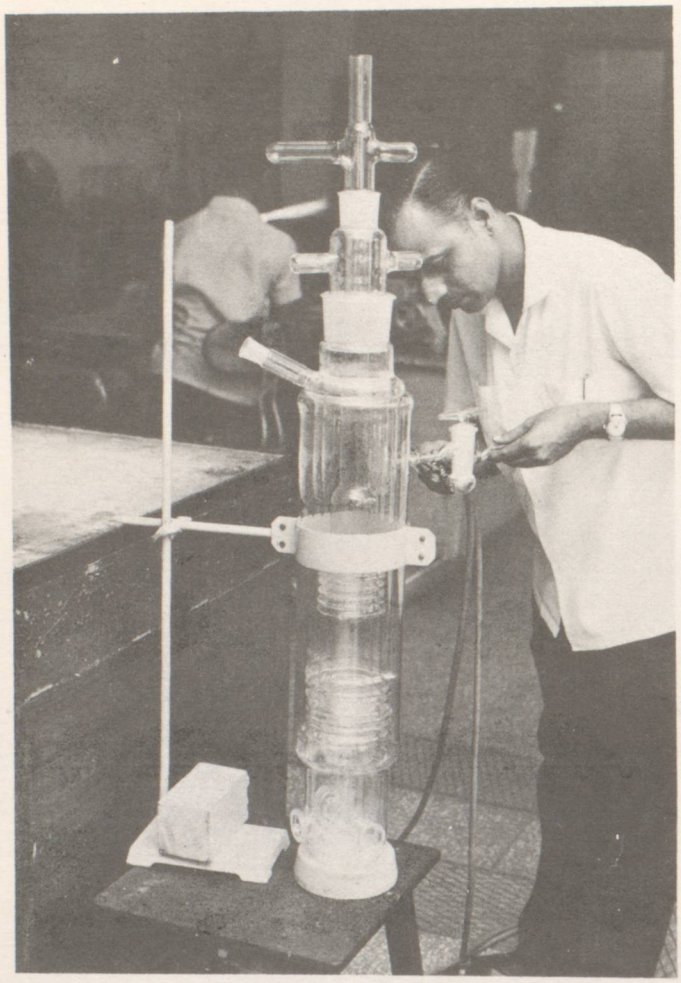


Fig. 4—A glass liquid helium cryostat in the final stages of its construction.

Complicated glass equipments have been fabricated for other institutions like the Indian Institute of Technology at Bombay; the India Meteorological Department, Poona; the Indian Institute of Science, Bangalore; the Bhabha Atomic Research Centre and various University Departments in the country.

The TIFR glass shop provides apprentice training in advanced glass blowing techniques.

MEDICAL FACILITIES

The Institute provides all staff members with *free* medical and dental care. In 1953, a small beginning was made by establishing a Medical Clinic at the Old Yacht Club building, (in which the Institute was then located), with Dr. J. P. Vazifdar as Honorary Physician. In 1954 the Clinic was strengthened with the appointment of additional full time medical officers. This Clinic served not only staff members of the Institute but also members of the Department of Atomic Energy and of the Atomic Energy Establishment, Trombay, that had just then been set up.

Medical Section

In 1960, the Institute established its Medical Section in the permanent buildings at Colaba with Dr. R. V. Jotwani as full time Medical Officer. The Clinic has two nurses and a ward boy on a full time basis. The Clinic functions from 9.30 a.m. to 5.30 p.m. on all working days; specific hours are allotted for routine treatment and for the compulsory annual medical check-up that staff members have to undergo.

At this Clinic free medical advice and aid is offered and necessary medicines are prescribed and issued. The Clinic has facilities for screening and diathermy therapy; it is shortly to be equipped with facilities for taking electrocardiograms. The Clinic carries out initial and annual medical check-ups in the case of every staff member, and arranges for pathological investigations to be carried out either at the BARC Pathological Laboratory or at professional pathological laboratories in the city.

Consultation

The Institute has a panel of consultants who charge a special rate of fees for professional services rendered. When necessary, the Medical Officer refers cases to these consultants in the various branches of medicine and surgery for opinion, treatment and therapy. All expenses incurred on this account are paid by the Institute. The Institute has treated these consultants (who are among the finest professionals in their areas in the city of Bombay) as though they were staff members of the Institute; and has throughout received excellent service and cooperation from them.

In cases of emergency or where they stay far away from the Institute, staff members are allowed to avail of medical treatment given by their family physicians or local doctors; and reimbursement is allowed provided the Medical Officer is kept fully informed concerning the illness and the treatment taken.

Lady staff members receive ante-natal and post-natal treatment, as also reimbursement of maternity expenses.

Hospitalisation and admission into nursing homes is arranged in all cases where surgical and/or in-patient ward treatment is considered necessary; the expenses incurred on this account are met by the Institute.

Dental Clinic

The Dental Clinic provides free dental care in the form of check-up, scaling, minor surgeries, fillings, dentures, etc. The Dental Clinic is under Dr. Fali S. Mehta, who is part-time Dental Surgeon on the staff of the Institute. The Dental Clinic has one part-time pathologist, two scientific assistants and one nurse on a full time basis. The Clinic is equipped with the latest equipment and appliances for dental treatment.

At present free medical and dental care is available *only* to the Institute staff members *and not* to members of their families. BARC and Department of Atomic Energy operate a Contributory Health Scheme under which, for a small monthly payment, free medical/dental care is available to all staff members *and* their families. It has been the intention to extend this scheme to the Institute, which is one of the institutions under the administrative purview of the Department of Atomic Energy, but this has not been possible so far. It is hoped that this will materialize soon.

WELFARE PROGRAMME

CO-OPERATIVE CREDIT SOCIETY LIMITED

The Tata Institute of Fundamental Research Employees' Co-Operative Credit Society Ltd. was established in 1958 with an authorised capital of Rs. 1 lakh. The paid-up capital at the end of the first financial year was Rs. 22,325/-subscribed by 241 members. At present the Society has 839 members on its register with a paid-up capital of Rs. 5 lakhs. The objects of the Society are to encourage thrift by enabling members to save part of their income in a safe and convenient way with the prospect of a fair profit and to prevent indebtedness by making loans available on reasonable terms.

During the 12 years of its existence, the Society has made allround progress. With the funds at its disposal the Society has been able to meet all the legitimate demands of the shareholders; the loans disbursed every month average over Rs. 30,000/-. The real worth of the Society, however, is more than what the figure reflects. It has been offering counselling and guidance to the economically weaker Sections of the Institute and has, on many occasions, gone out of the way to relieve members from the tyranny of money lenders. By offering this social service and by encouraging thrift, the Society has helped generate a sense of belonging in the members of the Institute.

The Society is run by a Managing Committee elected by the shareholders while the patronage of the Institute consists of administrative and organizational support. The Society looks forward to the opportunity of continuing and enlarging its service to its members in future.

BENEVOLENT FUND

The Benevolent Fund was set up in 1964 to give financial assistance to staff members of the Institute in cases of distress or hardship and to provide relief as may be necessary to the widows and dependents of ex-members. The fund also aims at carrying out measures of general welfare for the staff and their families including certain aspects of medical assistance.

Staff members of the Institute are encouraged to become members of the Fund and to contribute financially. The membership of the Fund stands at 1076 members (on 31.1.1971). Assistance provided by the Fund is, however, not limited to those who are members. The membership contribution is quarterly and is based on salary slab; the highest contribution is Rs. 10/- and the lowest Rs. 0.50 per quarter. Members at all levels can thus have a sense of belonging to and participating in a benevolent activity. There is also a provision for life membership. The Director of the Institute is the Patron of the Fund.

Apart from the membership contribution and donations, the earnings of the Fund also include a recurring contribution from the Council of the Institute which, for the present, is at the rate of Rs. 4/- per staff member and is based on the total staff strength as on March 31 every year.

The affairs of the Fund are managed by a Managing Committee which is nominated by the Director every 2 years. The Members of the Committee are drawn from major sections/groups so as to provide it with a wide base and an awareness of the hardships encountered by staff members of the Institute in various categories and salary levels.

The present activities of the Fund include financial assistance towards school fees for those not covered by the "Reimbursement of Tuition Fees" and the "Children Education Allowance" Schemes of the Institute; assistance is also given to staff members in the lower salary brackets towards cost of books and school uniforms for their children, provided the academic record of the student concerned is good. The Fund extends assistance to all members of the Institute towards expenditure involved in medical treatment for themselves and their families which is not covered under the Institute Medical Benefit Scheme; it also provides free spectacles for those in the lower income groups and subsidises a high protein diet for those afflicted by tuberculosis. Adhoc amounts are given by way of food subsidy for those who have to take leave on medical grounds on half pay or without pay.

The Fund is working on a new scheme for providing death benefits which, when implemented, will provide the dependents of a deceased member with a lump sum amount of about Rs. 1,000/- within a week from the date of the demise of the member.

SPORTS CLUB

The T.I.F.R. Sports Club was started in 1960 to cater to the sports interests of the Institute members. The Club aimed also at promoting social and welfare activities for the staff. The first Chairman was Professor M. G. K. Menon.

The outdoor games sponsored by the Club during the last several years include Tennis, Badminton, Volleyball, Cricket, etc. It has also organised a variety of indoor activities: Music circle, Books Library, Table Tennis, Carroms, Chess, etc. The Music circle arranges lunch hour sessions of recorded music which are very popular with many members. The social activities that have been organised include staging of plays, music performances and group excursions in which family members could also take part.

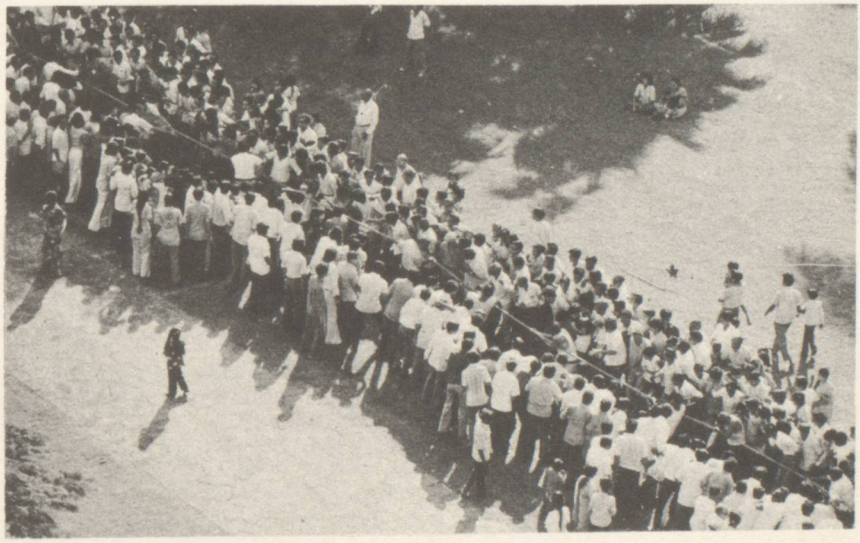


Fig. 1—A view of the tug of war event held on the Founder's Day.

AWARDS AND FELLOWSHIPS OF LEARNED SOCIETIES

	Fellowships of Learned Societies	Awards
Bhabha, H. J. (1909-1966)	Fellow, Royal Society, London Fellow, Indian Academy of Sciences Fellow, Indian National Science Academy Honorary Fellow, Gonville & Caius College, Cambridge Honorary Fellow, Royal Society of Edinburgh Honorary Fellow, American Academy of Arts & Science Fellow Member, World Academy of Arts & Science Foreign Associate, U.S. National Academy of Sciences General President, Indian Science Congress, 1949 President, International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1955	Senior Award, Royal Commission for the Exhibition of 1851 Adams Prize, 1942 Hopkins Prize, 1948 Padma Bhushan, 1954 *D.Sc. Honoris Causa* Patna University Lucknow University Banaras Hindu University Agra University Allahabad University Cambridge University London University Padova University
Chandrasekharan, K.	Fellow, Indian National Science Academy Fellow, Indian Academy of Sciences President, Mathematics Section, Indian Science Congress, 1957 Vice President, International Council of Scientific Unions (1962-1966)	Padma Shri, 1959 Shanti Swarup Bhatnagar Award, 1959
Daniel, R. R.	Fellow, Indian Academy of Sciences	
Dharmatti, S. S. (1911-1955)	Fellow, Institute of Physics, London Fellow, American Institute of Physics Fellow, Indian Academy of Sciences	
Kosambi, D. D. (1907-1966)	President, Mathematics Section, Indian Science Congress, 1947	
Lal, D.	Fellow, Indian Geophysical Union Fellow, Indian Academy of Sciences	Krishnan Medal of the Indian Geophysical Union, 1965
Menon, M. G. K.	Fellow, Royal Society, London Fellow, Indian Academy of Sciences Fellow, Indian National Science Academy	Senior Award, Royal Commission for the Exhibition of 1851 Padma Shri, 1961 Padma Bhushan, 1968 Shanti Swarup Bhatnagar Award, 1960 *D.Sc. Honoris Causa* Jodhpur University

	Fellowships of Learned Societies	Awards
Murthy, C. R. K.	—	Krishnan Medal of Indian Geophysical Union, 1970.
Narasimhan, M. S.	Fellow, Indian National Science Academy Fellow, Indian Academy of Sciences	
Narasimhan, R,	Fellow, Indian Academy of Sciences	
Pal, Yash	Fellow, Indian Academy of Sciences	
Peters, B.	President, Physics Section, Indian Science Congress, 1956 Fellow, Indian Academy of Sciences Fellow, Indian National Science Academy	
Rama	Fellow, Indian Academy of Sciences	
Raghavan Narasimhan	—	Racine Prize, 1963
Ramanathan, K. G.	Fellow, Indian National Science Academy	Shanti Swarup Bhatnagar Award, 1965
Ramanna, R.	Fellow, Indian Academy of Sciences President, Physics Section, Indian Science Congress, 1963	Shanti Swarup Bhatnagar Award, 1963
Seshadri, C. S.	Fellow, Indian Academy of Sciences	Narasinga Rao Gold Medal, 1957
Siddiqi, O.	Fellow, Indian Academy of Sciences	
Singbal, B. V.	—	Narasinga Rao Gold Medal, 1954
Singh, Virendra	Fellow, Indian Academy of Sciences	
Sreekantan, B. V.	Fellow, Indian Academy of Sciences	
Srinivasan, T. P.	—	Narasinga Rao Gold Medal, 1955
Swarup, G.	Fellow, Indian Academy of Sciences	
Thosar, B. V.	Fellow, Indian Academy of Sciences President, Physics Section, Indian Science Congress, 1969	
Udgaonkar, B. M.	Fellow, Indian Academy of Sciences	